# Minimum Functionality Habitation Element

**Lunar Surface Systems Workshop**
**US Chamber of Commerce, Washington, DC**
**25 February 2009**

SICSA
ILC DOVER creating what's next
Hamilton Sundstrand

# Final Presentation Agenda

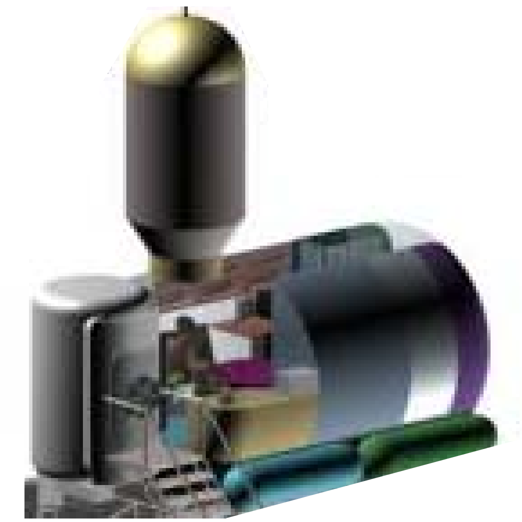
**Introduction**
- Study Team
- Study Goal and Approach
- Resultant Habitat Element

**Element Need Analysis**
- Reference Mission
- Requirements
- Minimum Functions and Rationale
- Interrelationships

**Subsystem Allocation and Development**
- Subsystems and Functions
- Highlight of Key Features
- System Level Configuration Development

**Final Configuration Concept**
- Habitat Element
- MEL

**Growth Options**



# Key Personal

- ILC Dover
  - John H.K. Lin
    *Design Engineering Manager*
  - Carl Knoll
    *Systems Engineering Manager*
  - Jon Hinkle
    *Design Engineer*
- Hamilton Sundstrand
  - Bryan Murach
    *Advanced Programs Manager*
  - Ben Bishop
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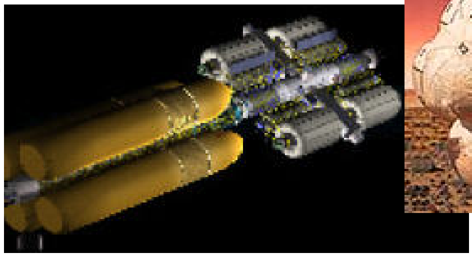
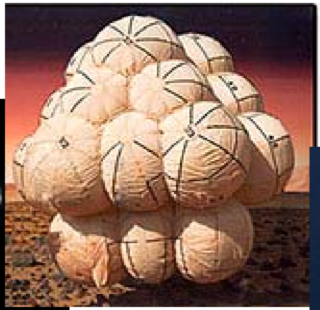
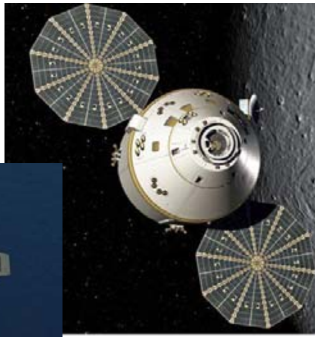
  - Larry Bell
    *Director/Professor of Space Architecture*
  - Olga Bannova
    *Research Assistant Professor*
  - Harmon Everett
    *M.S. Space Architecture*

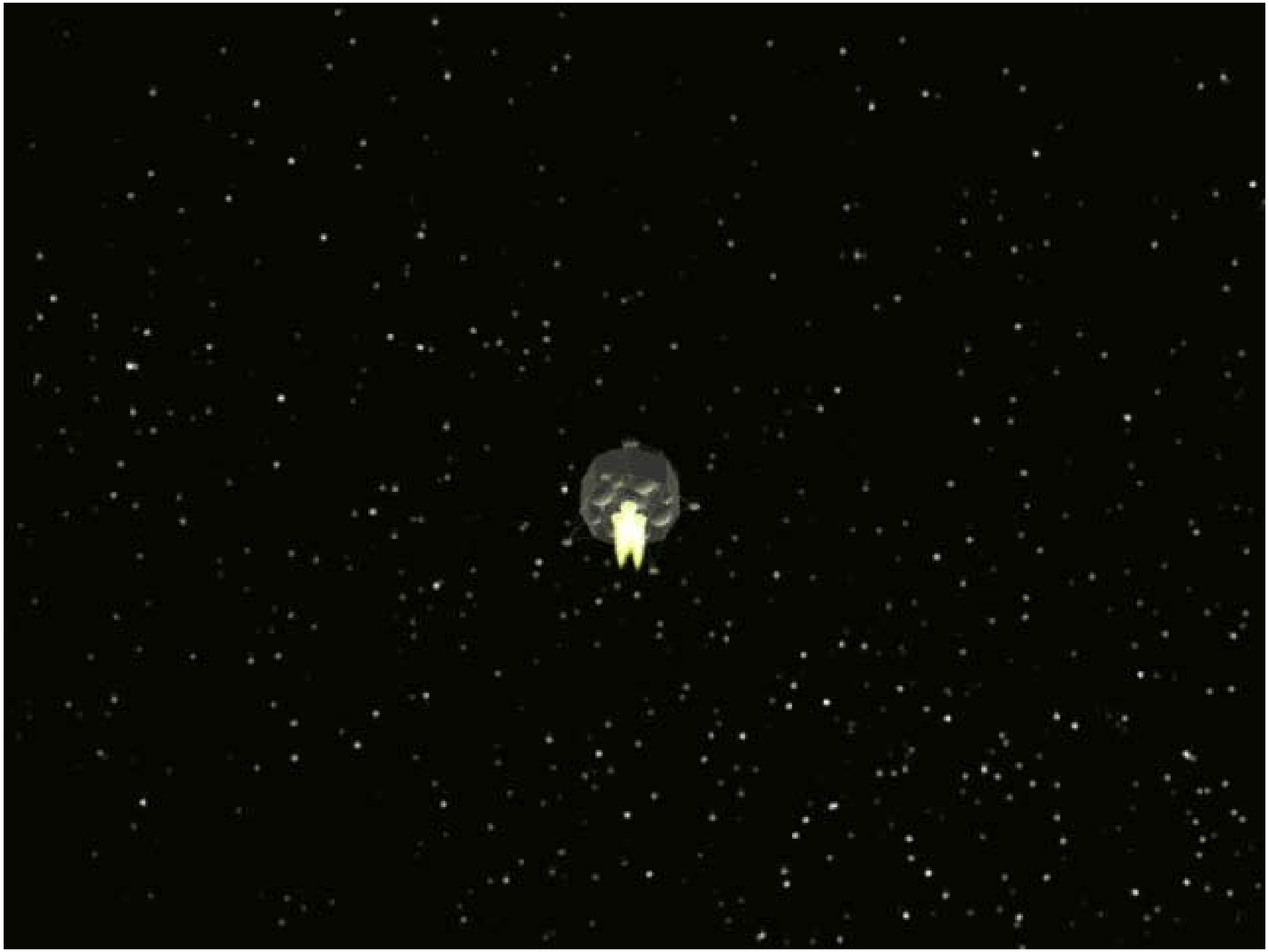


# Program Goal and Approach

*The combined expertise of ILC, HS, and SICSA will identify innovative and practical solutions for a minimum habitat system to support the NASA reference mission. The end result will be a conceptual design and definition of a 'bare bones' or minimum habitat element that incorporates the benefits of flexible materials.*

- Three Tier Approach
  - Baseline: Minimum functionality habitat element that utilizes expandable elements without changing the reference mission
  - Growth Option 1: Optional MFHE approach that utilizes expandable elements for increase volume within the reference mission
  - Growth Option 2: Enhance the reference mission by fully utilizing the benefits of the expandable design. This is no longer a minimum approach.

# MFHE Solution

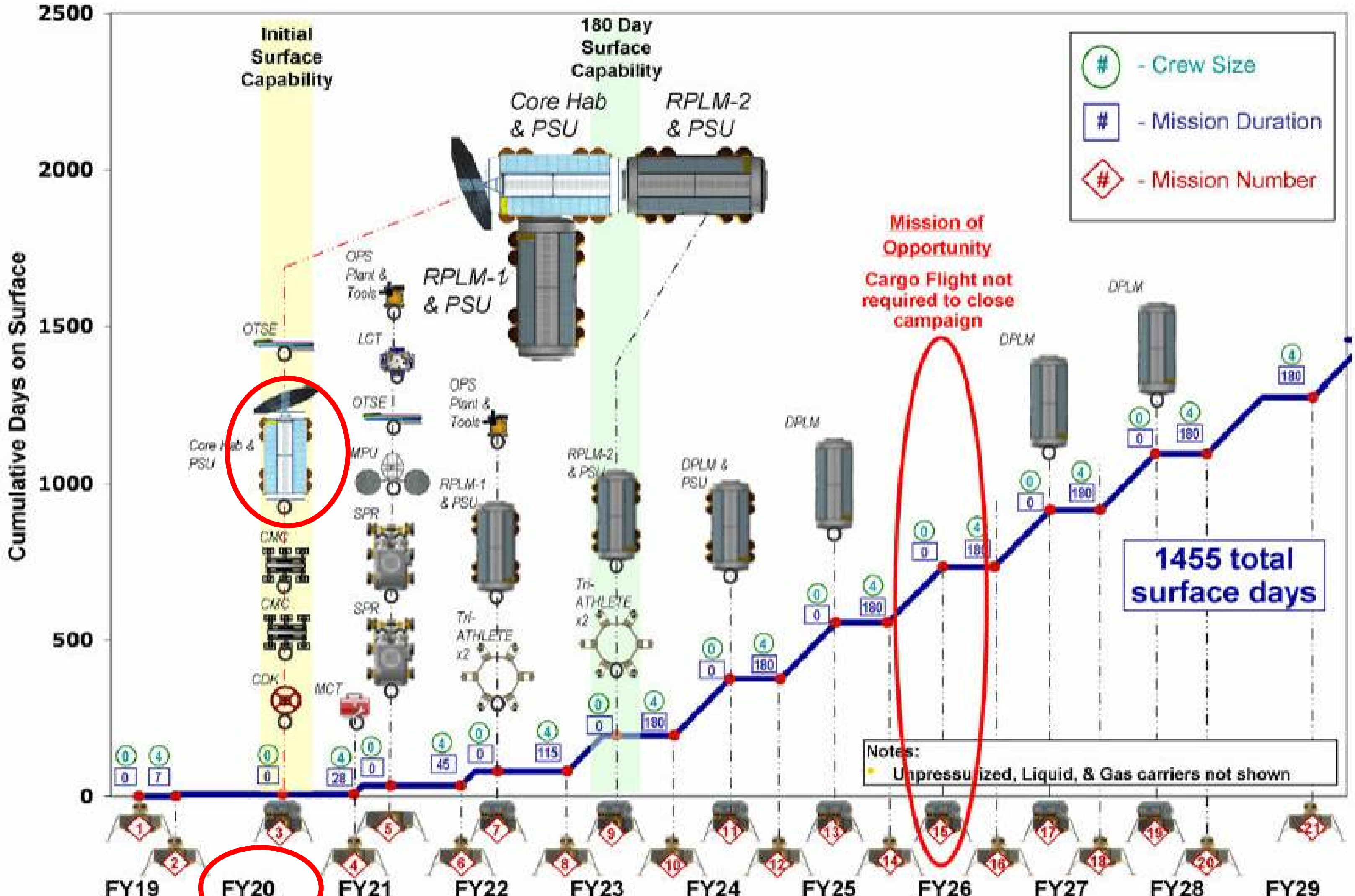


# Key Habitat Features

1. Minimum Volume
   – resource sharing and reconfiguration
2. Fabric Thermal Chimney
   – low mass and power thermal control, deployable
3. Airlock - Deployable & innovative air retention
   – increased available lander payload & minimizes air loss
4. Water-wall crew radiation protection
   – multi-use of resources
5. Life Support System
   – utilize crew EVA life support hardware
6. Communications and Processing
   – use Altair lander equipment

**Innovation, Resource Sharing and Multi-functionality are Key to Efficiency**

# Given Reference Mission – Scenario 4.0



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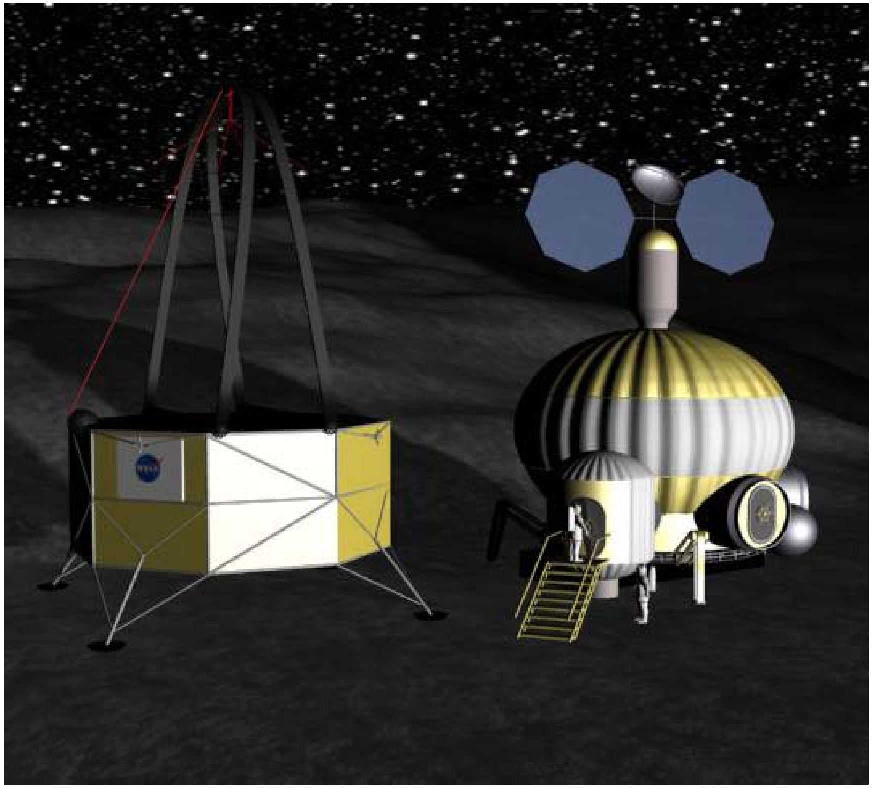
# Baseline Requirements

| Requirements | Source |
|---|---|
| **Crew size of four (4)** | BAA kick-off package |
| **28 day mission (on surface)** | BAA kick-off package |
| 10 - 15 year life | Q&A transcripts |
| Polar location | Q&A transcripts |
| Fit shroud size 8.8 m dia x 17.2 m tall. Usable volume of 860m3 | Q&A transcripts |
| Growth by internal capacity and/or external elements | BAA kick-off package |
| Habitat to Rover access in shirt sleeves | Q&A transcripts |
| 8 psi environment / 30% $O_2$ | Q&A's transcripts / BAA kick-off package |
| Habitat element reports health status to earth, pre crew arrival | Q&A transcripts / BAA kick-off package |
| Communications to support core module (habitat) | Q&A transcripts |
| Habitat element mass not to exceed 7000 kg - | BAA kick-off package |
| **Habitation element protects from radiation** | BAA kick-off package |
| Thermal control of the habitat | Q&A transcripts |
| **Support EVA operations (all aspects)** | Q&A transcripts |
| Habitat operates when crew not there | Q&A transcripts (other topics) |
| Up to 400 kg water available from lander | Q&A transcripts, BAA kick-off package |

# Growth Requirements

| Growth Requirements | Source |
|---|---|
| 180 day mission | BAA kick-off package |
| Eventual full time crew | BAA kick-off package |
| Up to 8 crew during change-out (undefined duration) | Q&A transcripts |



# Minimum Function Process

Mostly defined

**Mission Definition** (1)
- Crew size
- Duration
- Operations
  - Living
  - Science

We define next level

**Define Needs** (2)
- Living/working
- Supplies
  - Food
  - Life Support
- Subsystems
  - Mechanical
    - EVA suit
    - Tools
    - etc
  - Electrical
    - Power
    - Nav
    - Processing

We 'calculate'

**Size Needs** (3)
- Volume size
- Supplies
  - lbs. Food
  - expendables
- Subsystems / function
  - Mechanical
    - # EVA suits
    - Type/# tools
    - etc
  - Electrical
    - Watts
    - Nav requirements
    - Processing power/speed

We 'design'

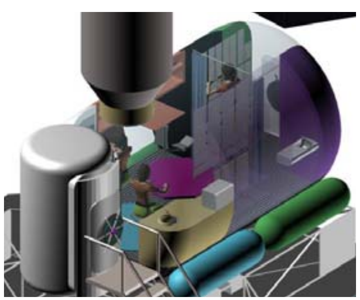
**Define Subsystem / Function Options** (4)
- Vertical / horizontal
- Supplies
  - Food type: grow / bring
  - Life Support
- Subsystems
  - Mechanical
    - EVA suit
    - Tools
    - etc
  - Electrical
    - Solar / Nuke
    - GPS / Beacon
    - Laptop / Cray

We 'combine'

**System Configuration Options** (5)
- Volume 1, LS 3, Power 2,…
- Volume 3, LS 4, Power 1,…
- Volume 2, LS 3, Power 1,…

**SYSTEM TRADES**

**Selected System Concept** (6)





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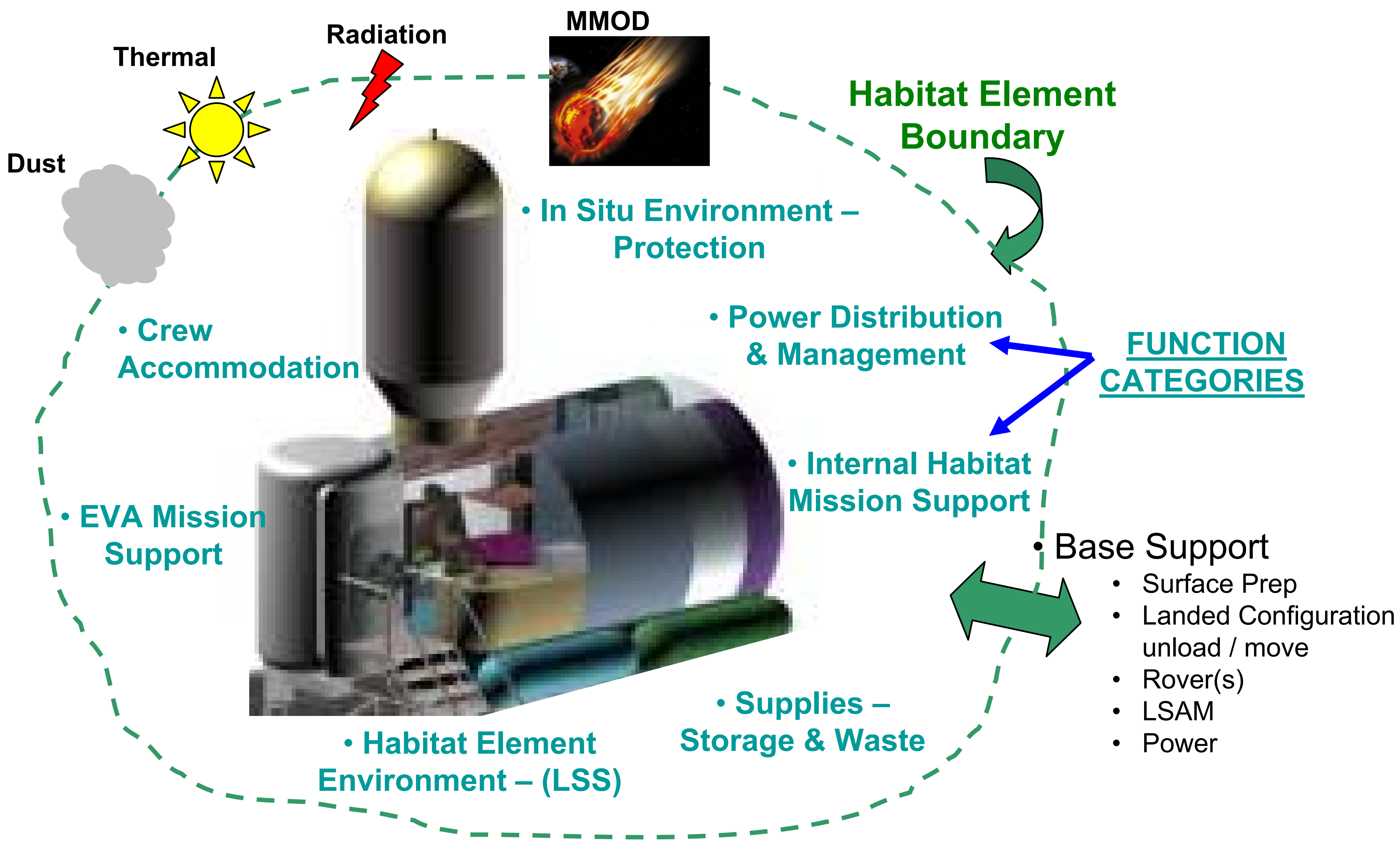
# Habitat Boundary and Minimum Function Categories

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# Design Considerations

| Consideration | Source / Rationale | Comments |
|---|---|---|
| 1/6 gravity | Lunar environment | Not a function but a design criteria |
| Vacuum | Lunar environment | Not a function but a design criteria, off gassing |
| Lunar surface preparation | Post lander removal | The habitat will interface with the PSU and that will have the direct interface with the lunar surface. No habitat requirements. |
| Habitat / PSU base interface | The habitat element will be supported by the PSU | This is both on and off the lander |
| PSU solar arrays | NASA architecture | The habitat will require an interface to the PSU solar arrays |
| Habitat lifting interface | For removal from lander | The PSU has the interface to the Tri-Athlete. |
| Launch vehicle envelope | NASA defined | Maximum |

# Minimum Functions Example

## *Environment*

| Function | Metric | Intra-related | External | Absolute minimum | Rationale |
|---|---|---|---|---|---|
| MMSE protection | Particle size, speed, # of, 0.97 probability of no penetration over 5 year | Volume, mass | Direction of exposure | Allows crew to get to ascent module | Crew Safety |
| Thermal control | Power/area, Acceptable internal temperature range | Hab internal thermal sources | Solar and deep space field of views | Equipment/ Personnel Range | Regulation for equipment operation and crew safety |
| Radiation protection | Radiation type / area / dose | Mass | Lunar environment | BFO = .002 Sv Eye=.003 Sv Skin = 6 Sv Testes = .001 Sv | Maintain equipment operation and crew health |
| Dust avoidance within habitat | Mass per event | EVA mission support | EVA suit and pressurized rover designs/configurations | Acceptable level of contaminant | Maintain equipment operation and crew health |

## *EVA Operations*

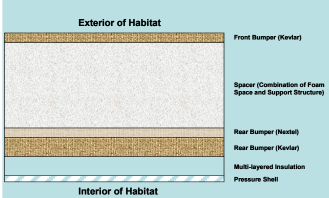
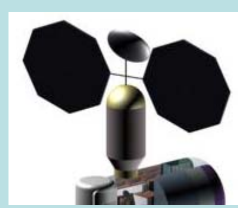
| Function | Metric | Intra-related | External | Absolute Minimum | Rationale |
|---|---|---|---|---|---|
| Suited Crew egress and ingress of habitat | Air loss per event | Dust mitigation | While on or off Lander | Size of entry/exit and suit interface | Reference Mission |
| EVA suit storage | Volume | Dust mitigation | EVA suit design and configuration | Volume allocated should not preclude other operations | Crew not always in suit |
| EVA suit maintenance / repair | Work area | Supplies | EVA system needs | Type and schedule of maintenance | Assumption from suit usage |
| Equipment transfer into / out of habitat | Size, frequency | Ingress / egress methods | Size and number of items | Size of equipment TBD | Supplies/Equipment will be needed |
| Crew shirt sleeve access to rover | | Commonality with docking interfaces | Habitat local ground conditions | Common docking interfaces | Reference Mission |

# Functionality / Subsystem Correlation

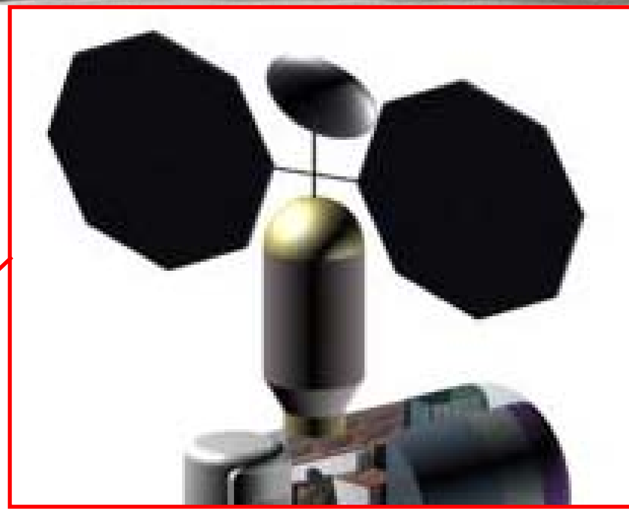
| Group | Functionality | MMSE Protection | Thermal Control | Radiation Protection | Dust Control | Habitat Air | Habitat Water | Waste Management | Food Processing | Habitat Monitoring | Hygiene Methods | Storage | Power Distribution | Space Suit Accommodation | Egress/Ingress Method | Habitat Volume / Configuration |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Environment Accommodation | MMSE Protection | | | | | | | | | | | | | | | |
| | Thermal Control | ++ | | | | | | | | | | | | | | |
| | Radiation Protection | + | + | | | | | | | | | | | | | |
| | Dust Control | | | | | | | | | | | | | | | |
| Habitat Environment | Habitat Air | | ++ | | + | | | | | | | | | | | |
| | Habitat Water | | | + | | + | | | | | | | | | | |
| | Waste Management | | | | | | ++ | | | | | | | | | |
| Habitat Operations | Food Processing | | | | | | ++ | + | | | | | | | | |
| | Habitat Monitoring | | +++ | +++ | + | +++ | +++ | + | | | | | | | | |
| | Hygiene Methods | | | | | | +++ | +++ | | | | | | | | |
| | Storage | | | ++ | | +++ | +++ | +++ | ++ | | +++ | | | | | |
| | Power Distribution | | + | | | | | | | + | | | | | | |
| | Space Suit Accommodation | | | | +++ | +++ | | | | | | +++ | | | | |
| System Level Configuration | Egress/Ingress Method | + | + | | +++ | +++ | | | | ++ | | ++ | | +++ | | |
| | Habitat Volume / Configuration | ++ | ++ | ++ | ++ | + | | | | | | ++ | ++ | ++ | +++ | |

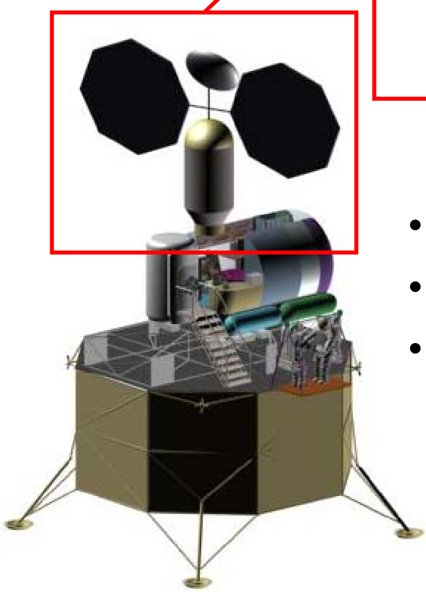
| Relation | Legend |
|---|---|
| +++ | Very Strong |
| ++ | Strong |
| + | Some |
| | Minimal |

# In-Situ Environment Protection

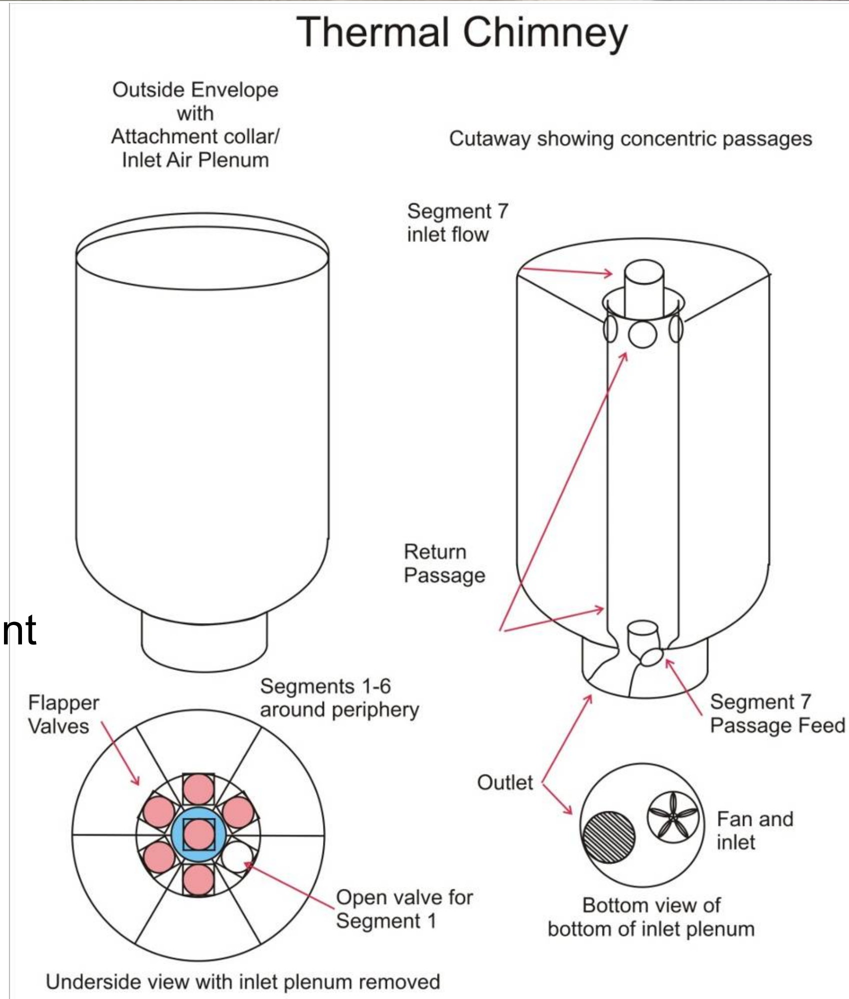
| Functions | MMSE Protection | Thermal Control | Radiation Protection | Dust Avoidance and Control |
|---|---|---|---|---|
| Proposed MFHE Solution | Kevlar Composite Whipple Bumper | Multi-layered Insulation & Thermal Chimney | Deployable Emergency Shelter for solar particle event | A Combined Approach |
| Other Concepts Considered | • Cover the habitat with Regolith<br><br>• Rigid shell or panel Whipple Bumper<br><br>• Deployable cover or shield<br><br><br> | • Cover the habitat with Regolith<br><br>• Insulation panels<br><br> | • Cover the habitat with Regolith (Bulk)<br><br>• Cover the habitat with Regolith in blanket or panel format (In-Situ mfg)<br><br>• Permanent water storage wall<br><br>• Polyethylene wall (localized application)<br><br>• Polyethylene blanket (reconfigurable localized and personal application)<br><br>• Polyethylene vest | • IVA operations with cleaning equipment and isolation bags<br><br>•Staging operations (suit cover and dust off area)<br><br>• EVA operations (protect all critical components)<br><br> |

# Deployable Thermal Chimney



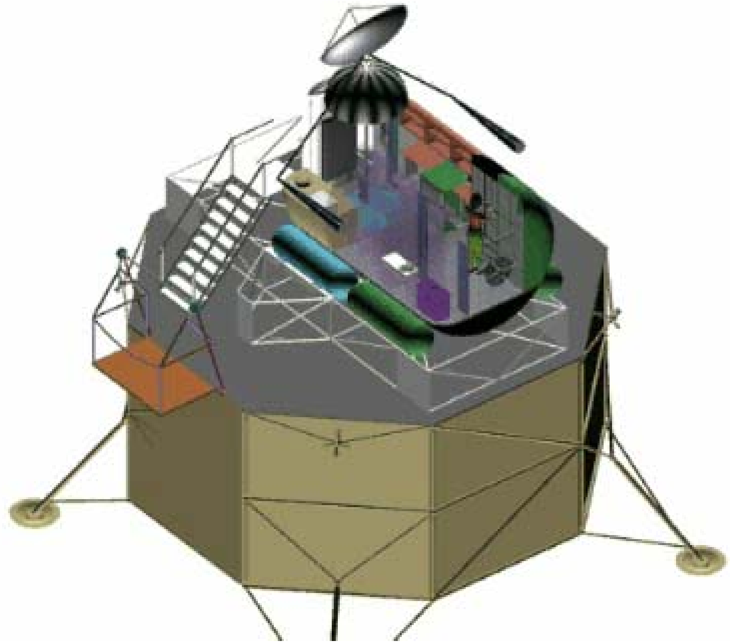


- Efficient thermal management
- Simple fan and valves
- Inflatable device lighter and simpler than liquid cooling system

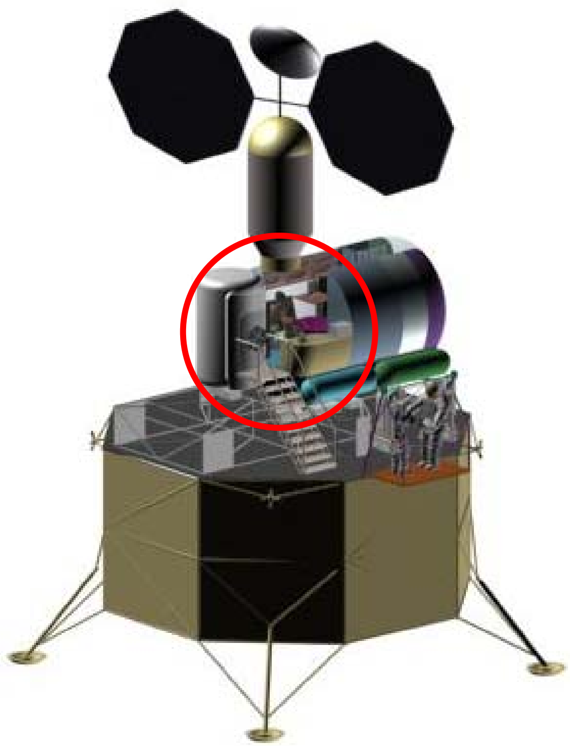


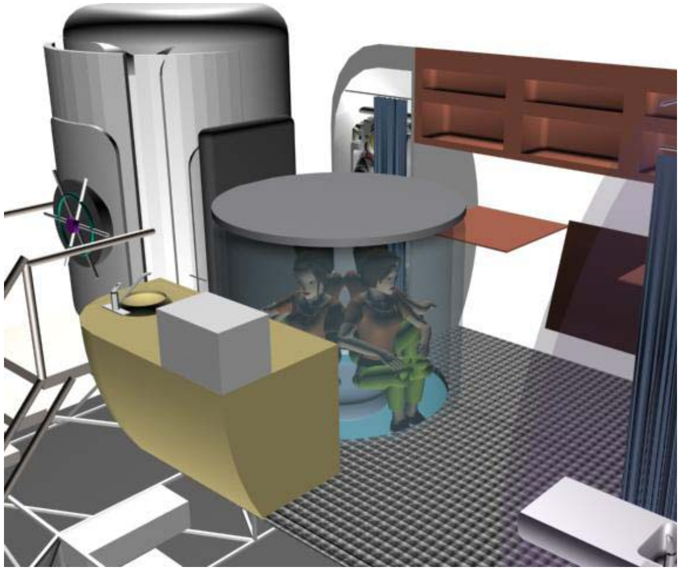

**Innovative Inflatable Thermal Chimney Simplifies System and Reduces Mass**

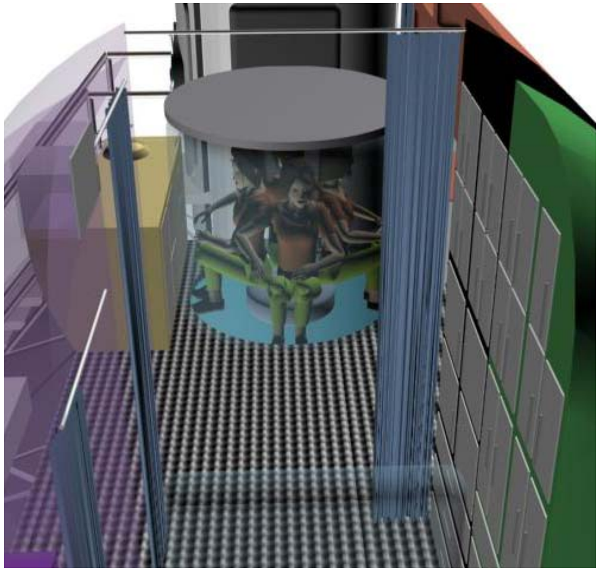
# Deployable Thermal Chimney Animation



# Deployable Water-Based Radiation Storm Shelter







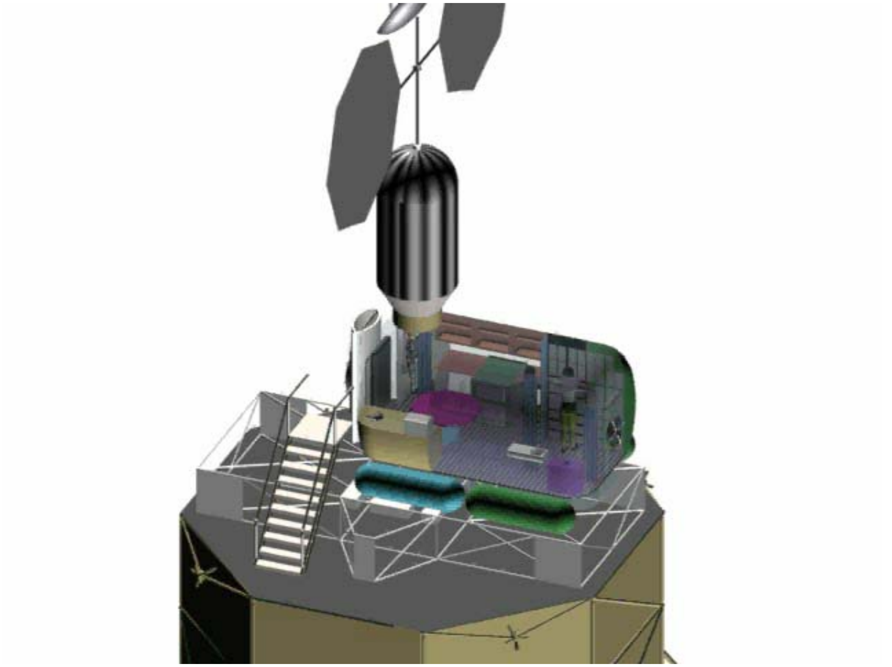
- Four-person, radiation protection storm shelter for solar particle event
- Water as the primary absorber, 2000 kg required
- Polyethylene mattress wall construction
- Deployed from the floor up
- Associated equipment (pump, bag storage), roughly 200 kg
- Transported frozen

**Multifunctional Use of Essential Resource Reduces Total System Mass**

# EVA Mission Support

| Functions | Suited Crew Egress and Ingress of Habitat | EVA Suit Storage | EVA Suit Maintenance and Repair | Equipment Transfer in and Out of Habitat | Crew Shirt Sleeve Access to Rover |
|---|---|---|---|---|---|
| Proposed MFHE Solution | Deployable Full Service 2 Person Airlock | Deployable Full Service 2 Person Airlock | Deployable Full Service 2 Person Airlock | Deployable Full Service 2 Person Airlock | Deployable Full Service 2 Person Airlock |
| Other Concepts Considered | • Suit port (rear entry)<br>• Door only (Apollo design, vent habitat)<br>• Small airlock (not full service)<br> | • Suit port (stored outside)<br>• Storage bag (inside habitat)<br> | • Service bag (inside habitat)<br>• Clean room (inside habitat)<br> | • Equipment transfer box<br>• Door only<br>• Service bag | • Door only (capable of docking with rover<br>• Small airlock<br> |

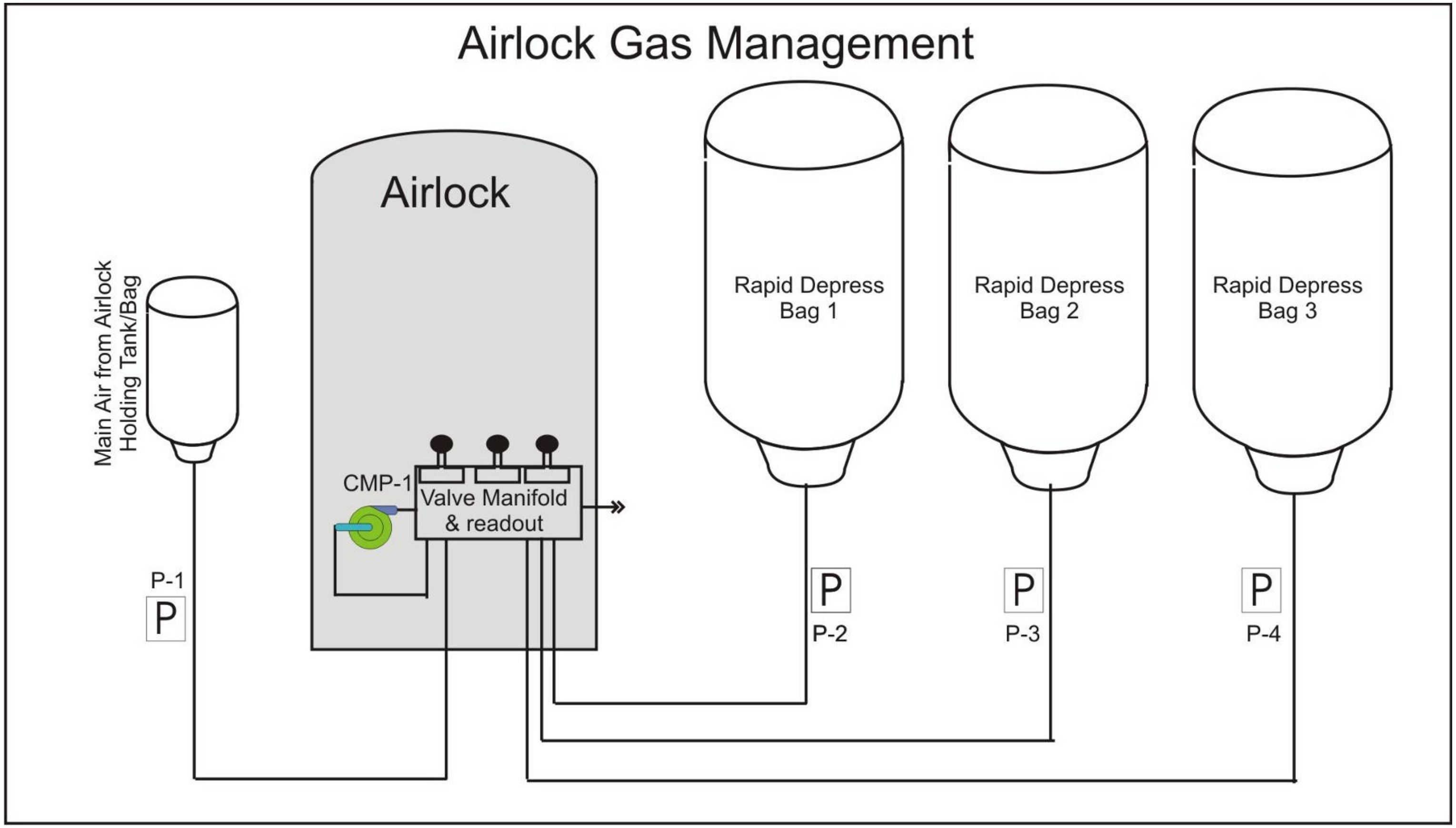
# Deployable Airlock



- 2 Person Airlock Design, 150 cm in diameter
- Small softgoods airlock minimizes mass impact
- All operations can be accomplished inside airlock envelope
- Deployable nature of the airlock allows it to be reconfigured for future growth options
- In an emergency situation all four astronauts can be inside the airlock

**Innovative Inflatable Airlock Reduces System Mass and Volume Impact**

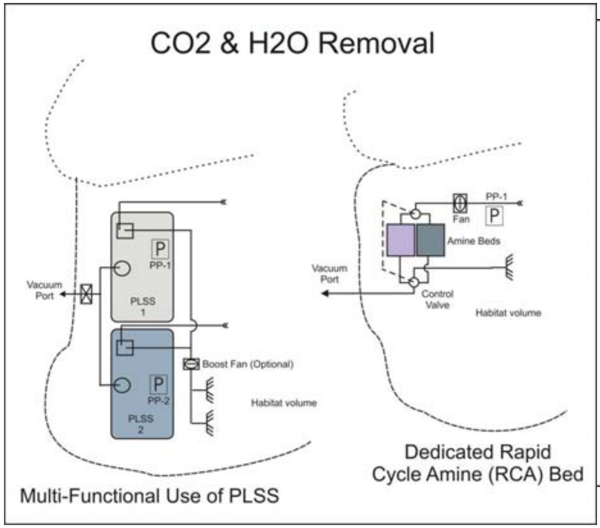
# Airlock Gas Management System



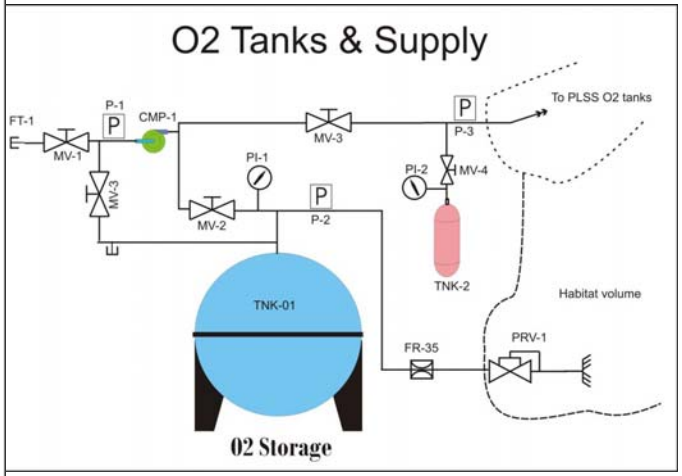

- Store depressurization air in softgoods bag
- Speed airlock depress using additional bags, recover air during idle time

**Innovative Softgoods Airlock System Reduces Operational Impact**

# Environmental Control and Life Support System (ECLSS)




**EVA PLSS Hardware**




**Habitat Augmentation**

- Primary Habitat ECLSS functionality provided by the crew EVA Portable Life Support Systems (PLSS)
- PLSS hardware interfaces with habitat element
- Habitat provides augmentation to PLSS and supplies expendable resources

**Maximum Utilization of Available Hardware**

# Volume Comparisons

- Vostok – 3 $m^3$ (106 $ft^3$) for single cosmonaut

- Mercury – 1.56 $m^3$ (55 $ft^3$) for single astronaut

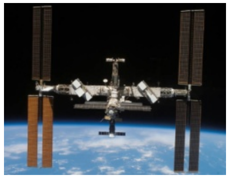
- Gemini – 2.26 $m^3$ (79.8 $ft^3$) for two astronauts

- Apollo – command module = 5.9 $m^3$ (208 $ft^3$) for 3 astronauts

- Skylab – total habitable volume of 283 $m^3$ (10000 $ft^3$) for 3 astronauts

- Shuttle – total habitable volume of 74 $m^3$ (2613 $ft^3$) for 7 astronauts

- MIR – total habitable volume of 150 $m^3$ (5297 $ft^3$) for 6 habitants



- ISS – 358 $m^3$ (12656 $ft^3$) of habitable volume to date (October 2008)

- Aquarius – total habitable volume of 81 $m^3$ (2863 $ft^3$)

# Area Comparisons

- Submarine – bunk is only personal space, stacked 3 high, 150 people

- Jail Cell – 8.9 $m^2$ (96 $ft^2$), 1 person, contains toilet, sink, bunk, table or shelf

- Railway Car – 3.7 $m^2$ (40 $ft^2$), contains twin bed (usually bunk bed), 1 or 2 people, fold down table, wash basin

- RV – 15 $m^2$ (160 $ft^2$), 3-5 people, contains queen bed, sofa bed, dinette, kitchenette, shower, overhead sleeping/storage

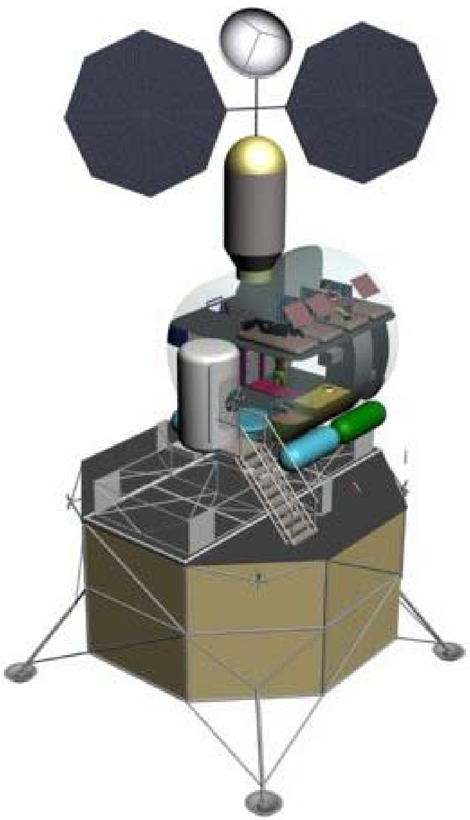
- Cruise Ship Room (Interior) – 17 $m^2$ (182 $ft^2$), 2 people, contains 2 twin beds, couch, dresser, 2 small closets, bathroom w/ shower

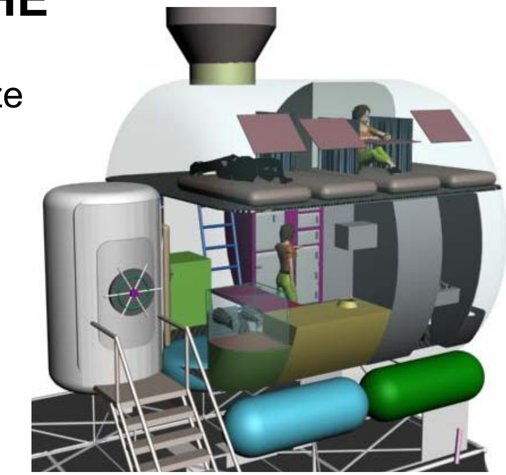
- Japanese Hotel Room – 12 $m^2$ (130 $ft^2$), 2 people, contains 1 double, dresser, bathroom w/ shower, small table, chairs

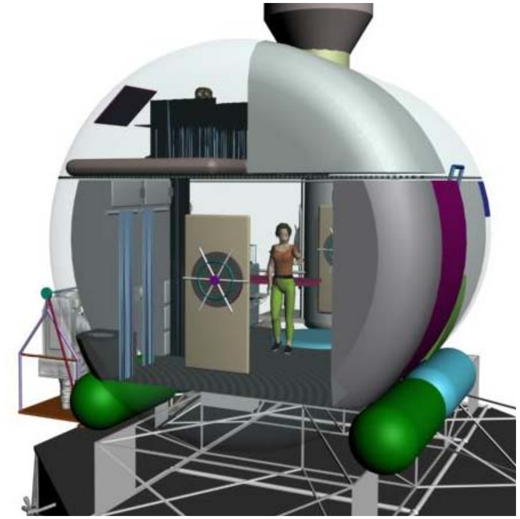
# Habitat Volume Configuration Trade Study

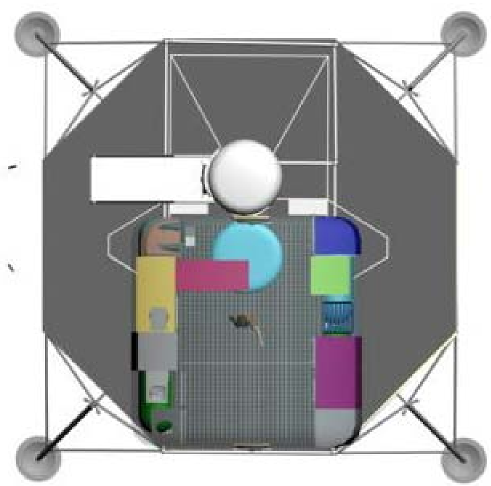
## 4.5 m Diameter x 4.5 m Long MFHE

- Initial floor plan and volume evaluation
- A viable option, but challenged to reduce size







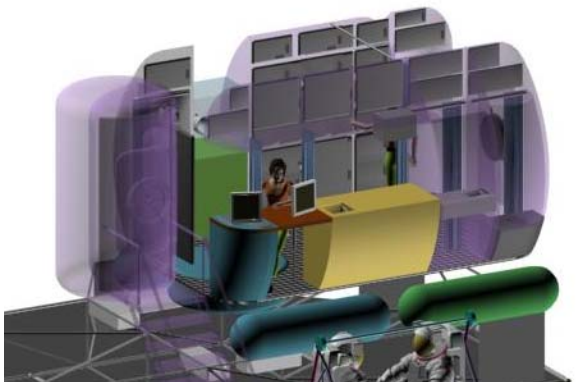


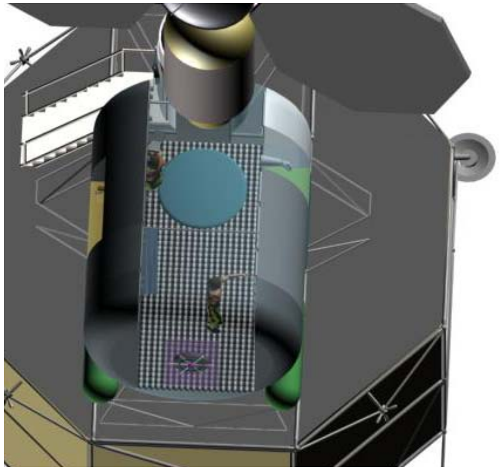
- Galley
- Folding Table
- Food Stowage
- Suit Stowage
- ECLSS/Gas Stowage
- Command/Com/Workstation
- Glove Box/EVA Stowage
- Water/Stormshelter
- Toilet
- Hygiene

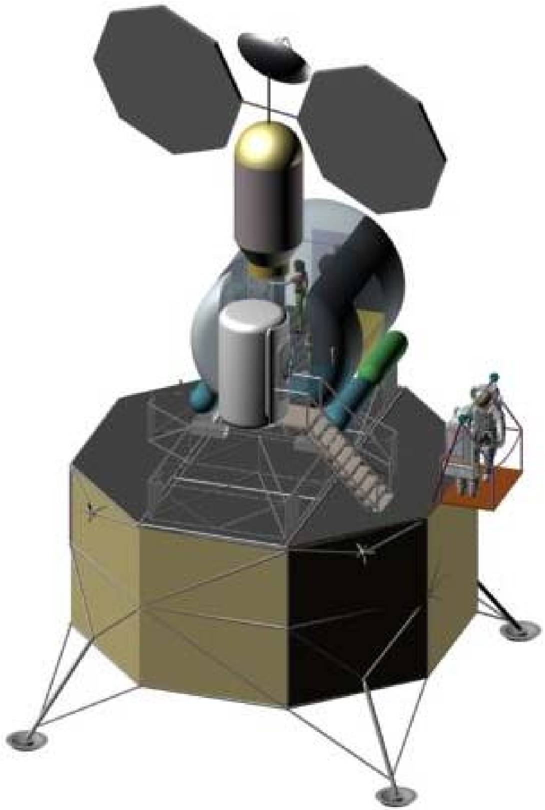
# Habitat Volume Configuration Trade Study

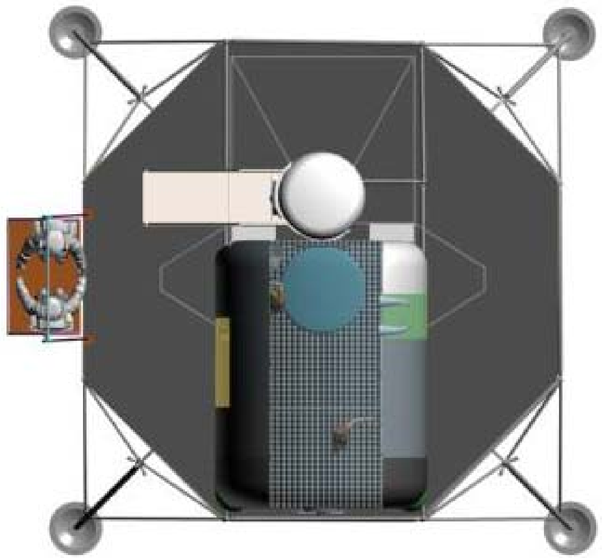
## 3.7m Diameter x 4.5 m Long MFHE

- Second iteration, another viable option
- Challenged to further reduce size







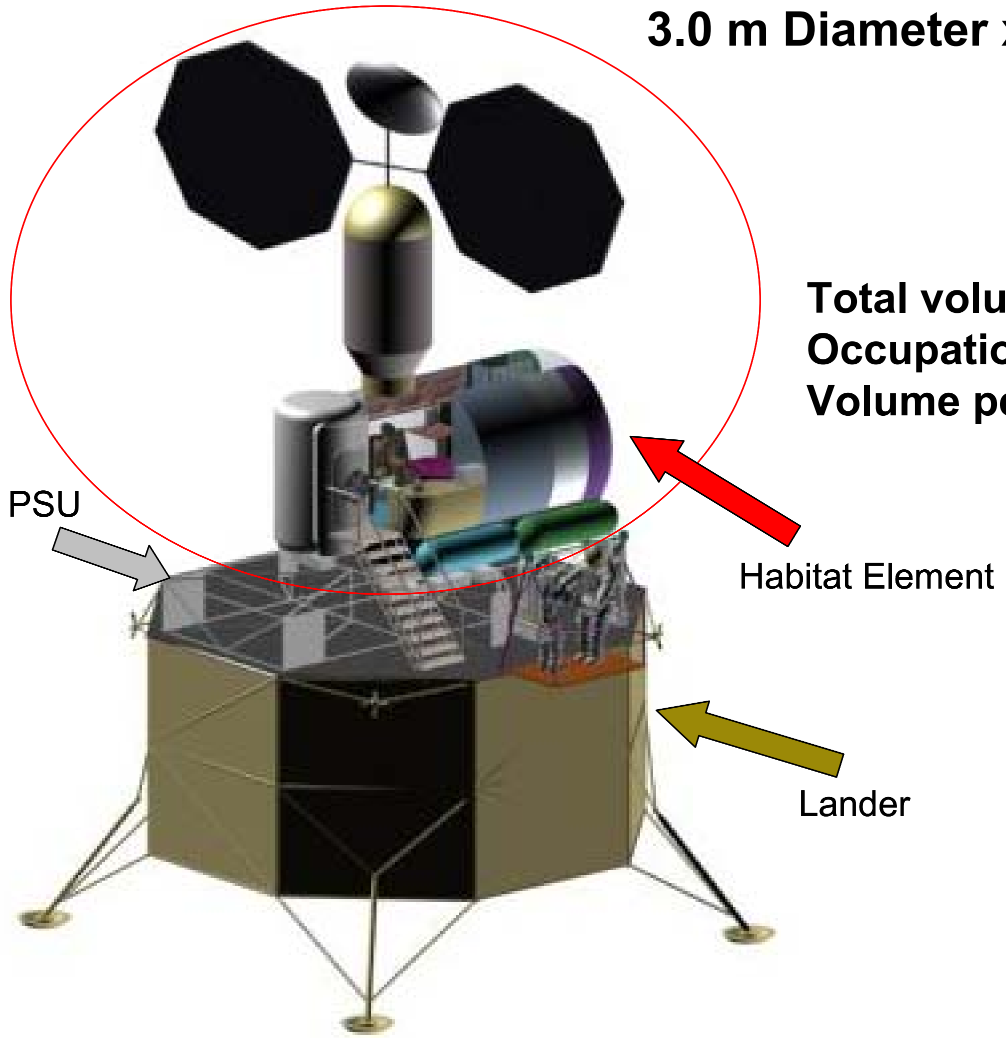


- Galley
- Folding Table
- Food Stowage
- Suit Stowage
- ECLSS/Gas Stowage
- Command/Com/Workstation
- Glove Box/EVA Stowage
- Water/Stormshelter
- Toilet
- Hygiene

# Baseline MFHE Configuration….

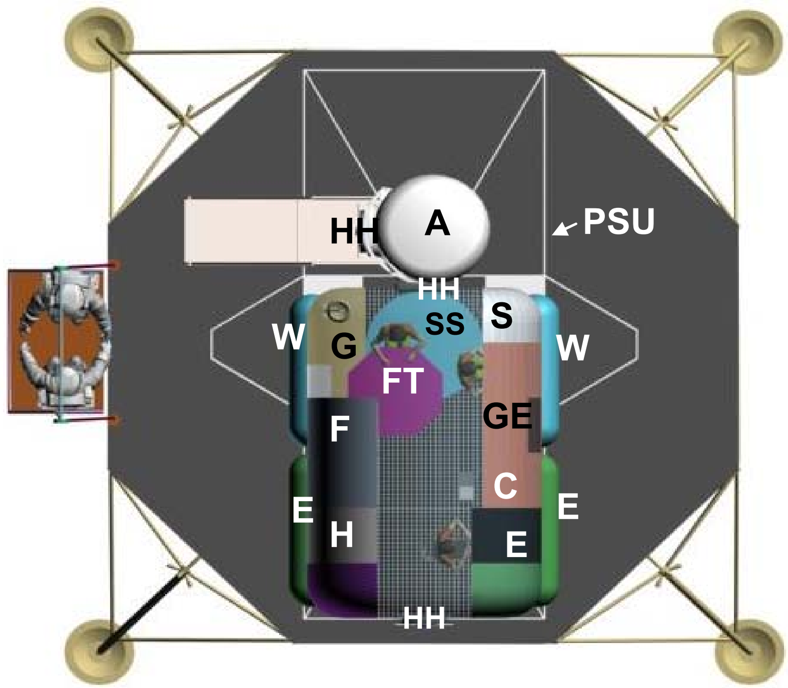
# Baseline MFHE

**3.0 m Diameter x 4.5 m Long MFHE**



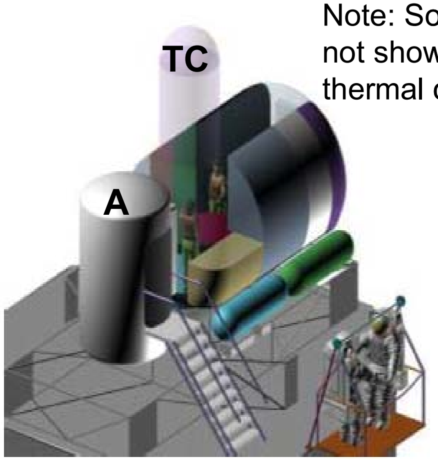

**Total volume = 30 $m^3$**
**Occupational volume = 20 $m^3$**
**Volume per crewmember = 5 $m^3$**

# Baseline MFHE




Note: Thermal chimney not shown in top view

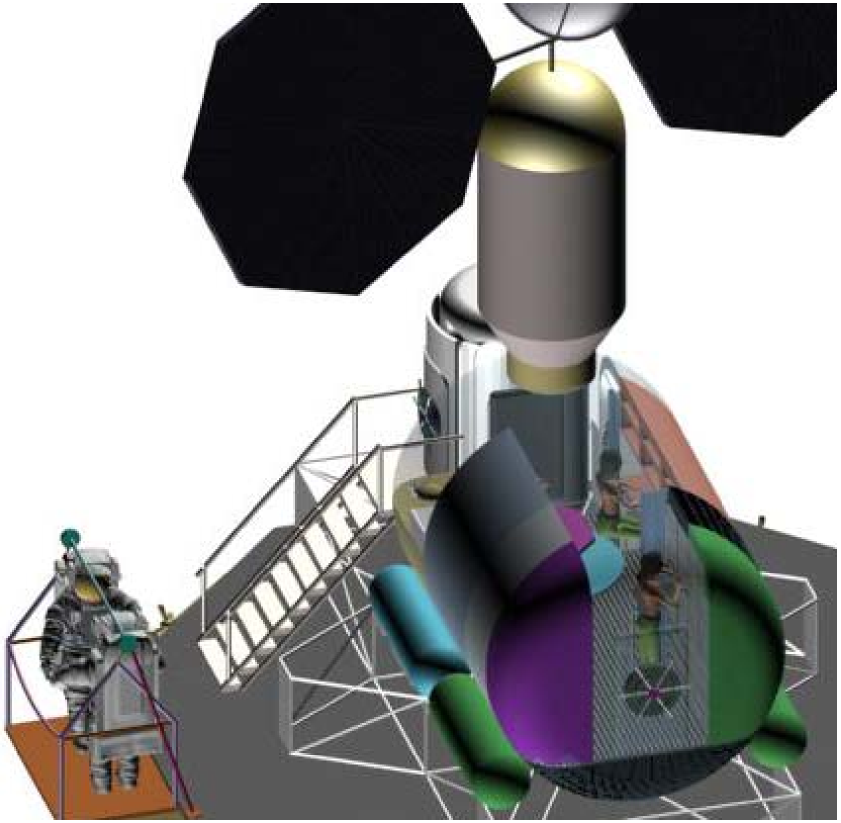
HH Hatch
PSU Power and Support Unit
A Airlock
G Galley
FT Folding Table
F Food Stowage
S Suit Stowage
E ECLSS/Gas Stowage
C Command/Com/Workstation
GE Glove Box/EVA Stowage
W/SS Water/Stormshelter
T Toilet
H Hygiene
TC Thermal Chimney

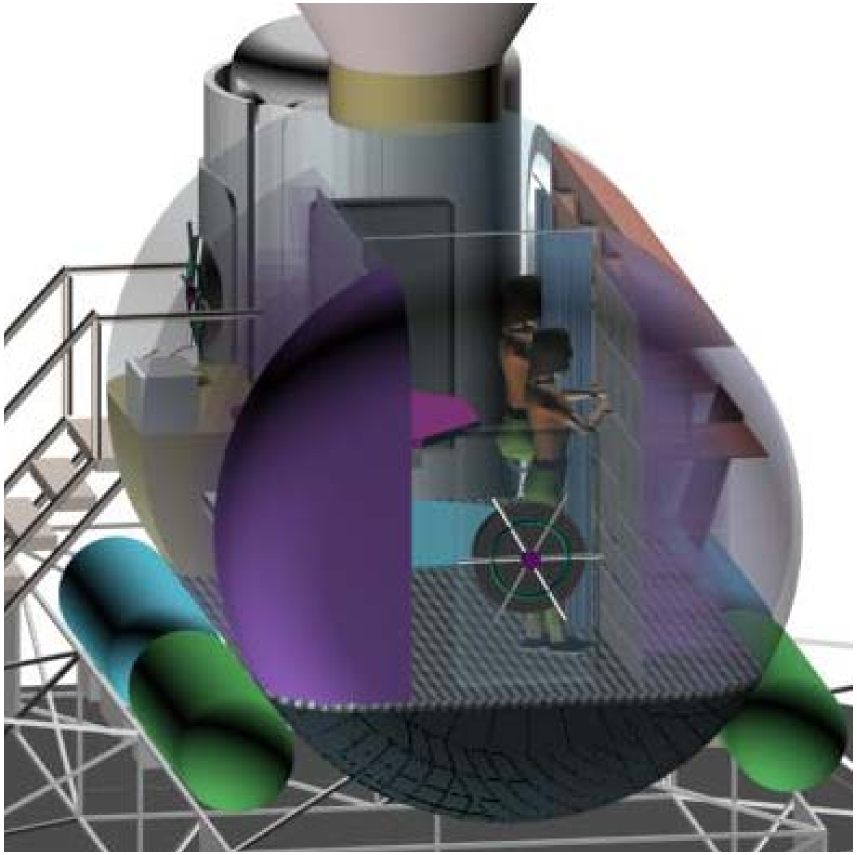



Note: Solar array not shown on thermal chimney

# Baseline MFHE

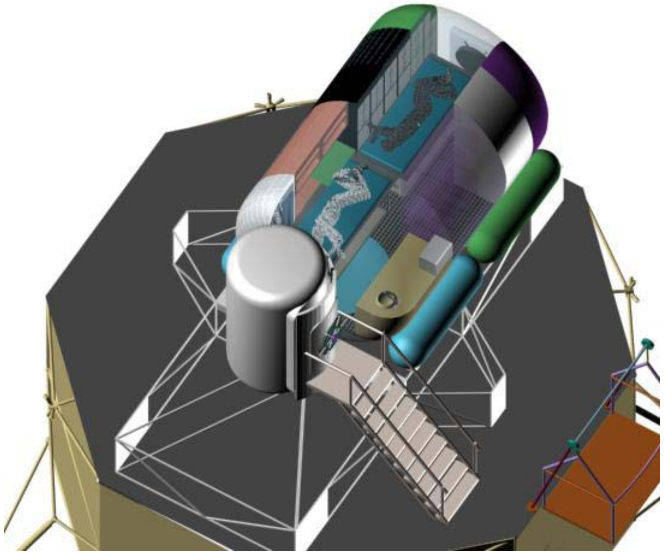
**3.0 m Diameter x 4.5 m Long MFHE**



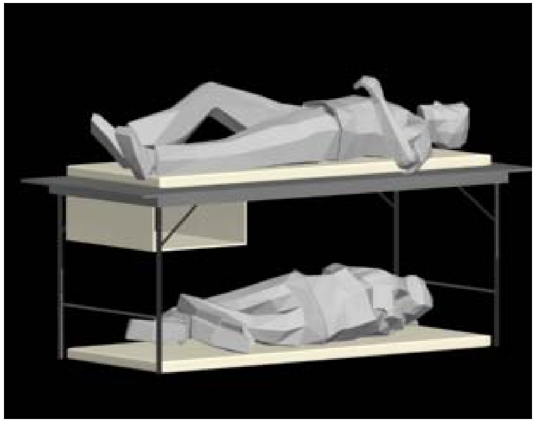


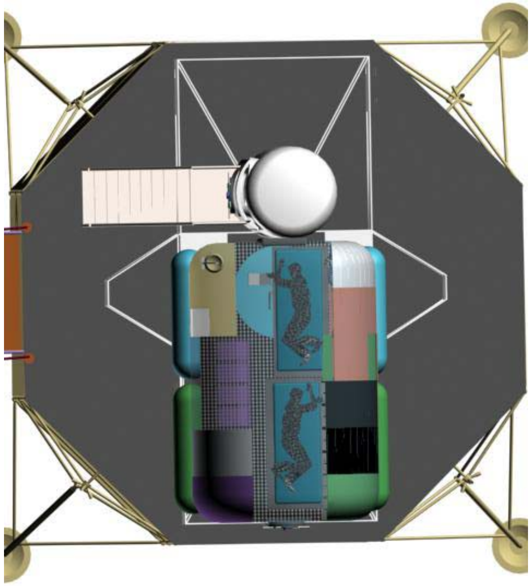
# Baseline MFHE

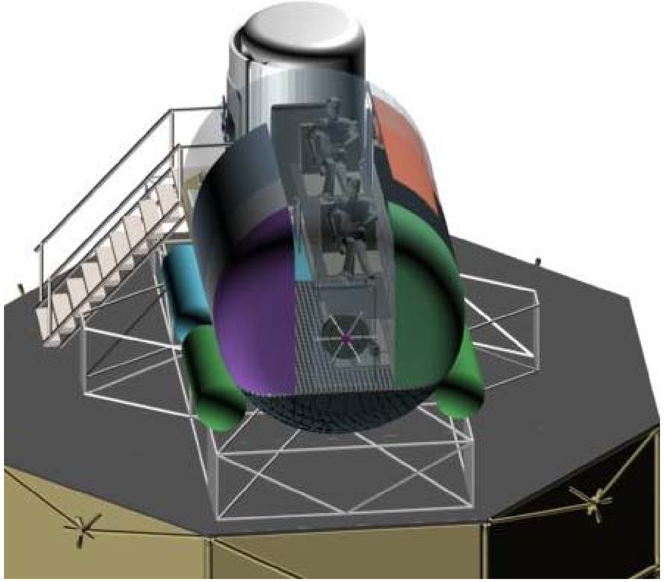
## Sleeping Layout



- Deployable bunk bed arrangement
- Accommodates four crew
- Utilizes multifunctional area









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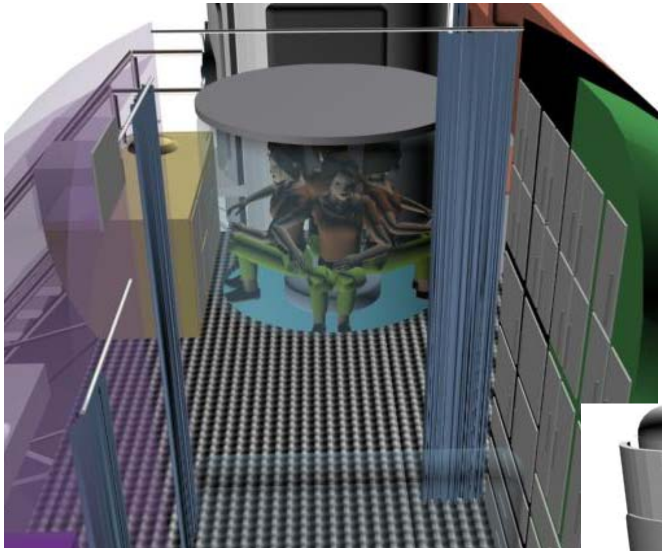
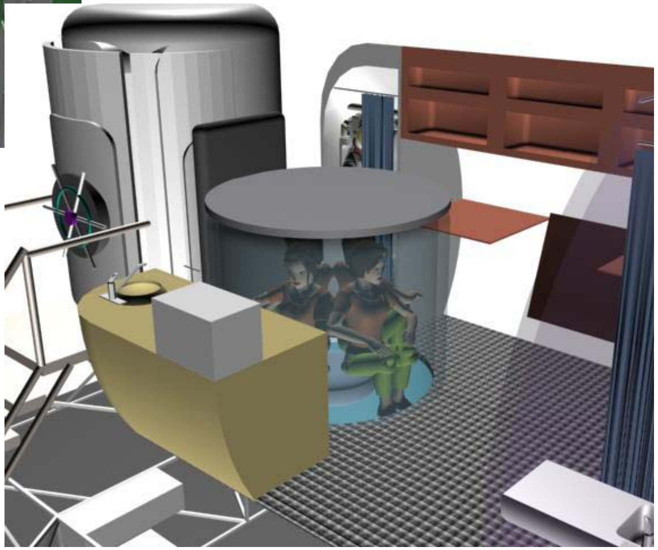
## Pop-Up Radiation Shelter



System stored underneath the floor



# MEL

| Item Information: | | | | Mass Estimate (kg): | | |
|---|---|---|---|---|---|---|
| Line No. | Item | Description/Comment | Qty / System | Item | System | Basis of Estimate |
| 1 | **Minimum Function Habitat Element** | | | | **5648.31** | |
| | | | | | | |
| 2 | **Habitat Structure** | | | | 892.80 | |
| 3 | Gas Retention Structure | 3/16" aluminum shell | 1 | 698.00 | 698.00 | SICSA Estimate |
| 4 | Habitat Floor | Grated floor | 1 | 194.80 | 194.80 | Fibergrate Estimate |
| | | | | | | |
| 5 | **MMSE Protection** | | | | 370.38 | |
| 6 | MMSE Fabric Cover | Kevlar composite, Nextel, whipple bumper | 1 | 370.38 | 370.38 | ILC Engineering Estimate |
| | | | | | | |
| 7 | **Thermal Control** | | | | 85.00 | |
| 8 | MLI | Outside | 1 | 50 | 50.00 | Engineering Estimate |
| 9 | Thermal Chimney | Primary means of ECLSS thermal control | 1 | 35.00 | 35.00 | Softgoods Mass Chart |
| | | | | | | |
| 10 | **Radiation Protection** | | | | 252.64 | |
| 11 | Water Wall Shelter | Polyethylene wall | 1 | 20.00 | 20.00 | Density = .920 g/cm^3 |
| 12 | Shelter Pump System | Pump for water wall | 1 | 200.00 | 200.00 | ILC Engineering Estimate |
| 13 | Personal Vests | Polyethylene vest with layers | 4 | 8.16 | 32.64 | ILC InFlex Program |
| | | | | | | |
| 14 | **Dust Control** | | | | 2.27 | |
| 15 | Suit Brush | Cleaning after EVA | 1 | 0.25 | 0.25 | Engineering Estimate |
| 16 | EVA Suit Bags | Dust control for suits inside habitat | 2 | 1.01 | 2.02 | Engineering Estimate |
| | | | | | | |
| 17 | **ECLSS** | | | | 462.94 | |
| 18 | Air Ducts | From PLSS | 20 | 0.10 | 2.00 | HS Engineering Estimate |
| 19 | PLSS Boost Fan | Allowing PLSS to supply habitat | 1 | 4.55 | 4.55 | HS Engineering Estimate |
| 20 | Nitrogen | Compressed | 2 | 8.16 | 16.32 | 2 Missions |
| 21 | Nitrogen Tanks | Storage Tank | 1 | 21.93 | 21.93 | Tank and Equipment |
| 22 | Oxygen | Compressed | 2 | 97.93 | 195.86 | 2 Missions |
| 23 | Oxygen Tanks | Storage Tank | 1 | 196.83 | 196.83 | Tank and Equipment |
| 24 | CO2 Scrubber | In addition to PLSS | 1 | 15.45 | 15.45 | Using 2 PLSS with helper fan and duct |
| 25 | Trace Contaminate Filter | In addition to PLSS | 1 | 10.00 | 10.00 | HS Engineering Estimate |

# MEL

| | | | | | | |
|---|---|---|---|---|---|---|
| 26 | **Habitat Water** | | | | 2918.52 | |
| 27 | Water | Consumables and Water Wall minus 400 kg from Lander | 1 | 2500.00 | 2500.00 | HS and ILC Engineering Estimate |
| 28 | Potable Water Tank | Storage | 1 | 357.52 | 357.52 | HS Engineering Estimate |
| 29 | Grey Water Tank | Storage | 1 | 50.00 | 50.00 | Store in bags (light tankage) |
| 30 | Water Ducts | Pumping | 1 | 4.00 | 4.00 | HS Engineering Estimate |
| 31 | Water Valves | Pumping | 2 | 2.00 | 4.00 | HS Engineering Estimate |
| 32 | Water Pumps | Pumping | 1 | 3.00 | 3.00 | HS Engineering Estimate |
| | | | | | | |
| 33 | **Food Processing** | | | | 268.28 | |
| 34 | Stored Food | Wet and Dry Food | 1 | 267.68 | 267.68 | HS Engineering Estimate |
| 35 | Consumption Equipment | Utensils | 4 | 0.15 | 0.60 | Engineering Estimate |
| | | | | | | |
| 36 | **Habitat Monitoring** | | | | 2.67 | |
| 37 | Computer | Laptop | 2 | 1.04 | 2.08 | Dell Mini9 Laptop |
| 38 | 02/N2 Sensor | Small COTS | 1 | 0.10 | 0.10 | Engineering Estimate |
| 39 | Humidity Sensor | Small COTS | 1 | 0.10 | 0.10 | Engineering Estimate |
| 40 | Temperature Sensor | Small COTS | 1 | 0.05 | 0.05 | Engineering Estimate |
| 41 | Pressure Sensor | Small COTS | 1 | 0.14 | 0.14 | Honeywell Part Estimate |
| 42 | Caution and Warning | Simple light system | 1 | 0.20 | 0.20 | Engineering Estimate |
| | | | | | | |
| 43 | **Storage** | | | | 50.42 | |
| 44 | Hygiene Wet Wipes | For cleaning and toilet operations | 1 | 26.14 | 26.14 | HS Engineering Estimate |
| 45 | Dry Towels | Hygiene Management | 1 | 5.00 | 5.00 | HS Engineering Estimate |
| 46 | Human Waste Collection | Urine and Solid collection | 1 | 7.28 | 7.28 | HS Engineering Estimate |
| 47 | Trash Bags | Wet and Dry Bags | 1 | 1.00 | 1.00 | HS Engineering Estimate |
| 48 | Clothing | Needed for thermal flux | 1 | 3.50 | 3.50 | Engineering Estimate |
| 49 | Suit Parts | EVVA and gloves | 1 | 7.50 | 7.50 | ILC Current Suit Estimate |

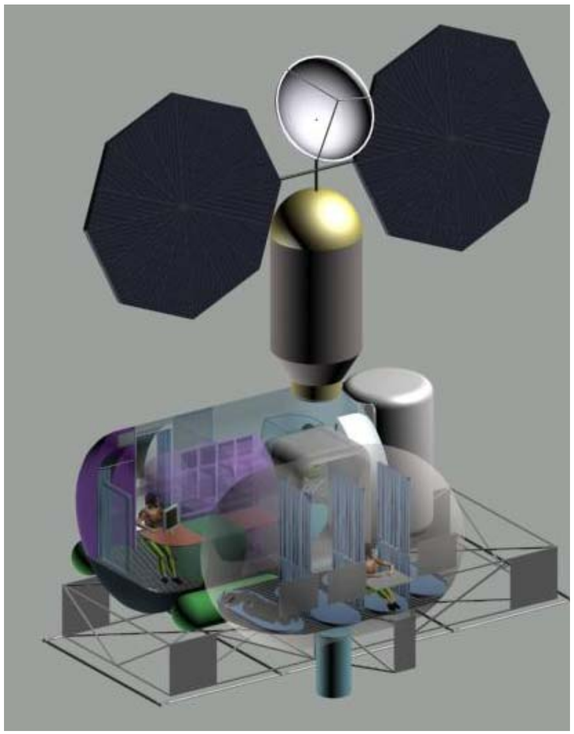
# MEL

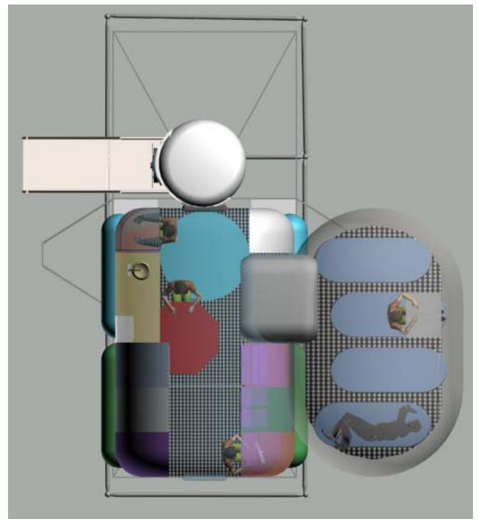
| | | | | | | |
|---|---|---|---|---|---|---|
| 50 | **Power Distribution** | | | | 3.57 | |
| 51 | Power Cord | Distribution system | 2 | 0.98 | 1.96 | Engineering Estimate |
| 52 | Outlets | Simple COTS power strip | 2 | 0.68 | 1.36 | Phillips Estimate |
| 53 | Breakers/Controls | Power control | 1 | 0.25 | 0.25 | Engineering Estimate |
| | | | | | | |
| 54 | **Ingress/Egress Method** | | | | 312.22 | |
| 55 | Airlock Structure | Softgoods structure | 1 | 4.10 | 4.10 | Softgoods Mass Chart |
| 56 | Floor | Grated flooring | 1 | 22.00 | 22.00 | Fibergrate Estimate |
| 57 | Airlock Hatch | Common hatch | 2 | 68.04 | 136.08 | ILC InFlex Phase 1 |
| 58 | Habitat Hatch | Common hatch | 1 | 68.04 | 68.04 | ILC InFlex Phase 1 |
| 59 | Don/Doff Stands | Aluminum stand for suits | 2 | 12.00 | 24.00 | Engineering Estimate |
| 60 | Compressor | Gas Reclamations and Depress System | 1 | 10.00 | 10.00 | HS Engineering Estimate |
| 61 | Air Bags | Gas Reclamations and Depress System | 1 | 10.00 | 10.00 | HS Engineering Estimate |
| 62 | Valve Assembly | Gas Reclamations and Depress System | 1 | 8.00 | 8.00 | HS Engineering Estimate |
| 63 | Piping | Gas Reclamations and Depress System | 1 | 10.00 | 10.00 | HS Engineering Estimate |
| 64 | Suit Recharge Interface | Gas Reclamations and Depress System | 2 | 10.00 | 20.00 | HS Engineering Estimate |
| | | | | | | |
| 65 | **Crew Accommodations** | | | | 26.60 | |
| 66 | Lighting | LED system | 4 | 3.50 | 14.00 | HS Engineering Estimate |
| 67 | Sleep Accommodations | Sleeping bags in common area | 4 | 1.02 | 4.08 | Western Mountaineering |
| 68 | Furnishings | Folding table | 1 | 1.00 | 1.00 | |
| 69 | Exercise Equipment | Small tension device | 1 | 5.00 | 5.00 | NASA recommendation |
| 70 | First Aid Kit | Small basic kit | 1 | 0.52 | 0.52 | Boy Scout/US Army Estimate |
| 71 | JSC Toilet | Waste Bag system | 1 | 2.00 | 2.00 | |

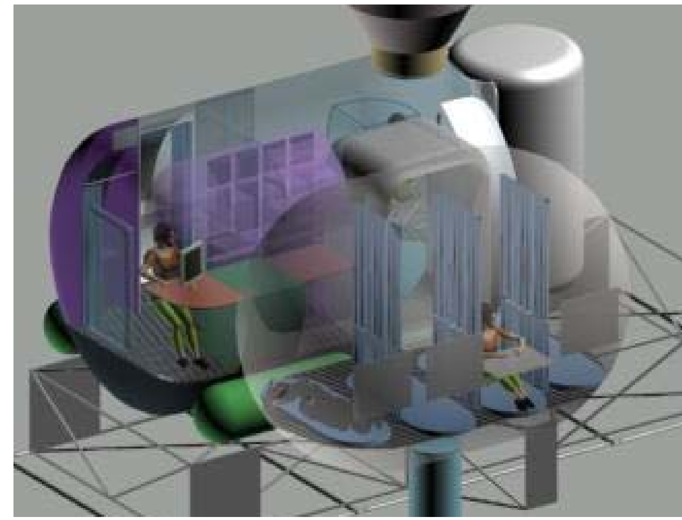
# Growth Options

# Tier 1 Growth Option

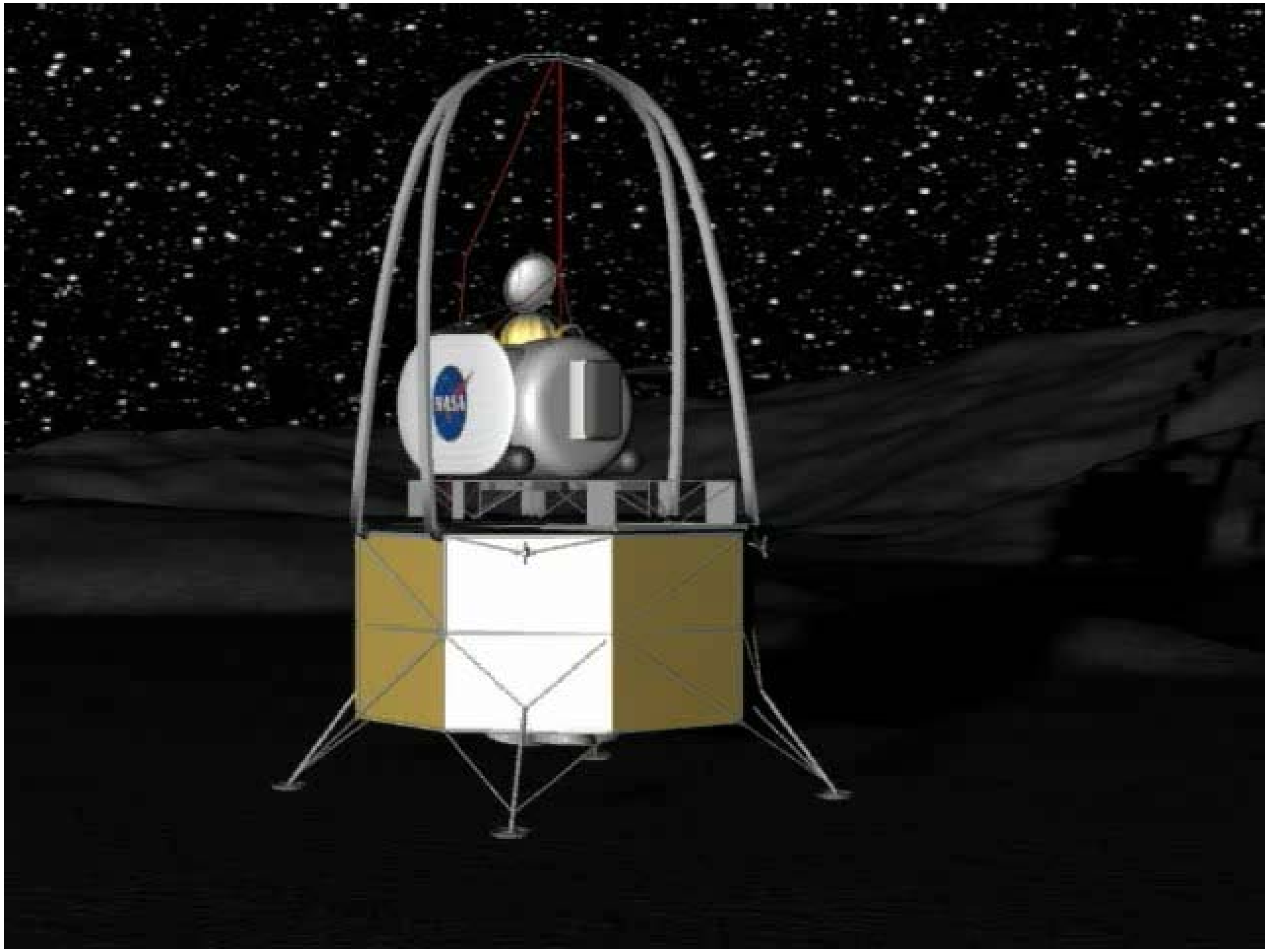
## 3 m Diameter MFHE with Expandable Side Pod





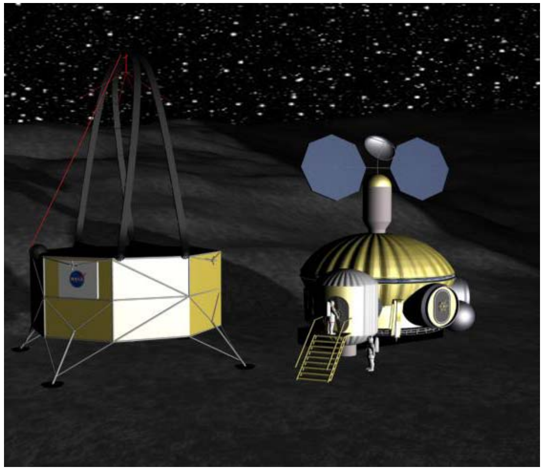


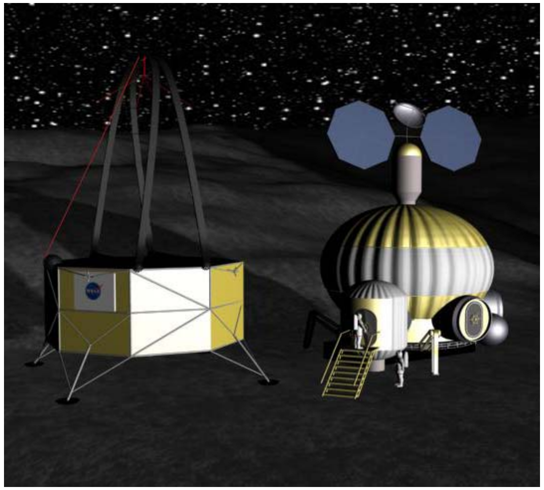
- Galley
- Folding Table
- Food Stowage
- Suit Stowage
- ECLSS/Gas Stowage
- Command/Com/Workstation
- Glove Box/EVA Stowage
- Water/Stormshelter
- Toilet
- Hygiene

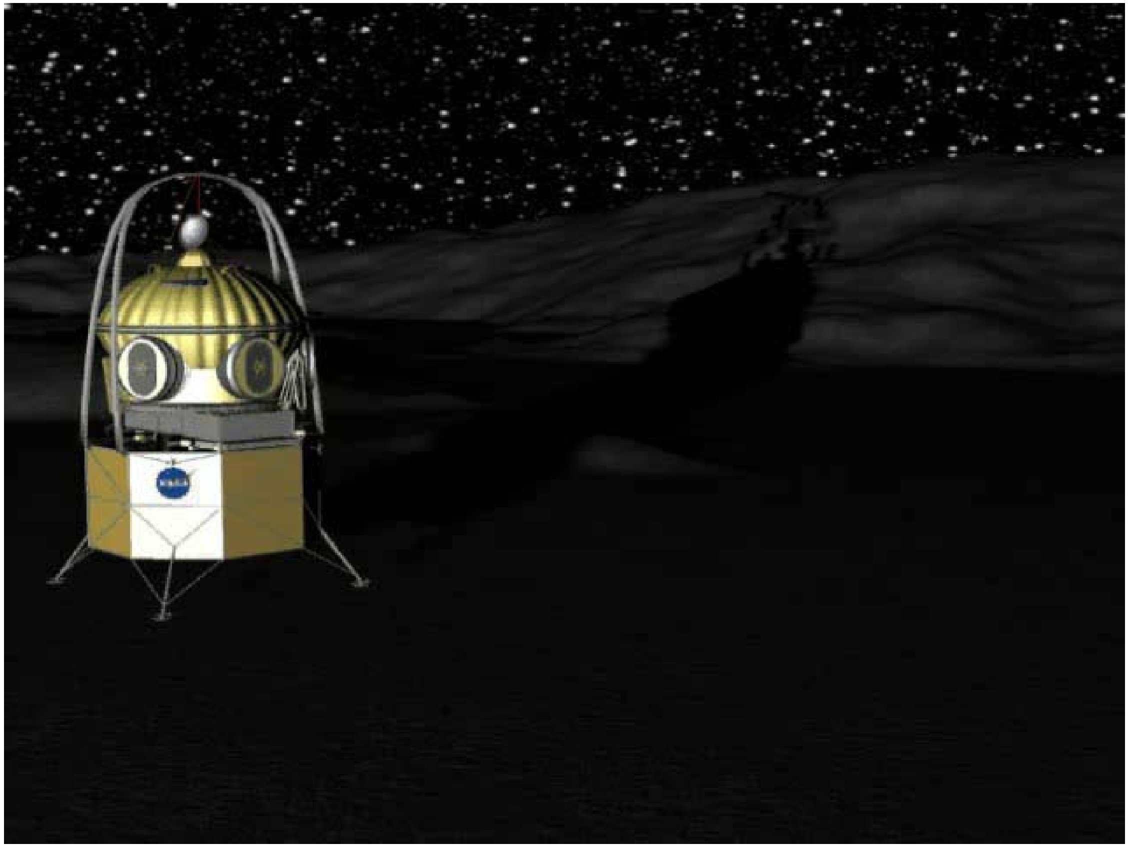


# Tier 2 Growth Option

## Crew Lunar Accommodations Module (CLAM)









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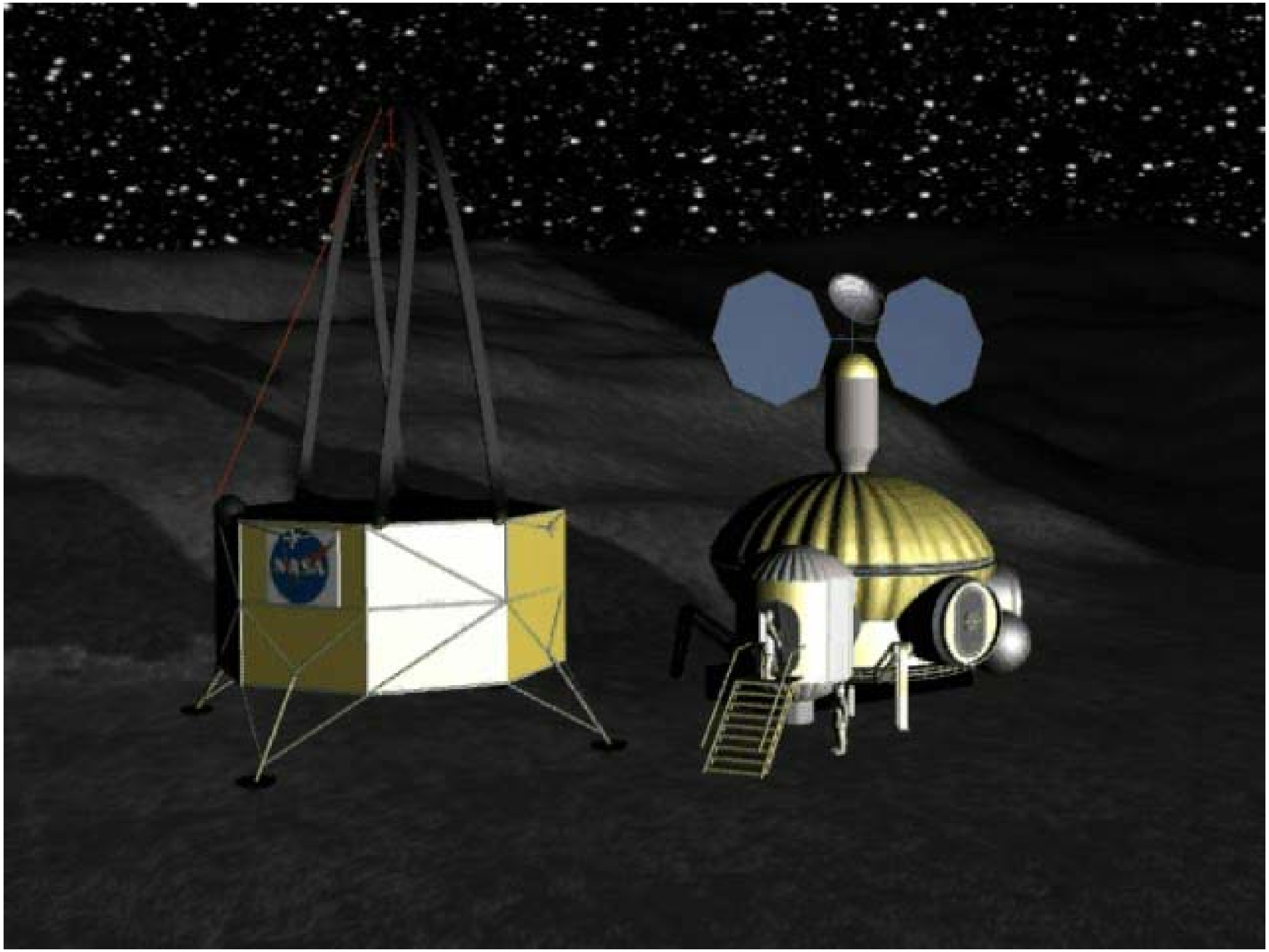
# Path Forward

- Focus on development of Key Features
  - **Volume allocation**
    - Analyze crew operations and habitat space requirements to optimize reconfiguration and dynamic reallocations
  - **Thermal Chimney**
    - Analyze further the efficiency, sizing and operation as an integral part of a thermal system
  - **EVA PLSS utilization**
    - Work with PLSS designers to evaluate incorporating the habitat requirements into the portable system
  - **Water wall radiation protection**
    - Continue concept development to evaluate the configuration and operational options of the shelter
  - **Deployable Airlock**
    - Continue the configuration studies and validate air reclamation concept
  - **Lander communication and processing systems utilization**
    - Work with the lander designers to evaluate the interfaces and requirements impacts





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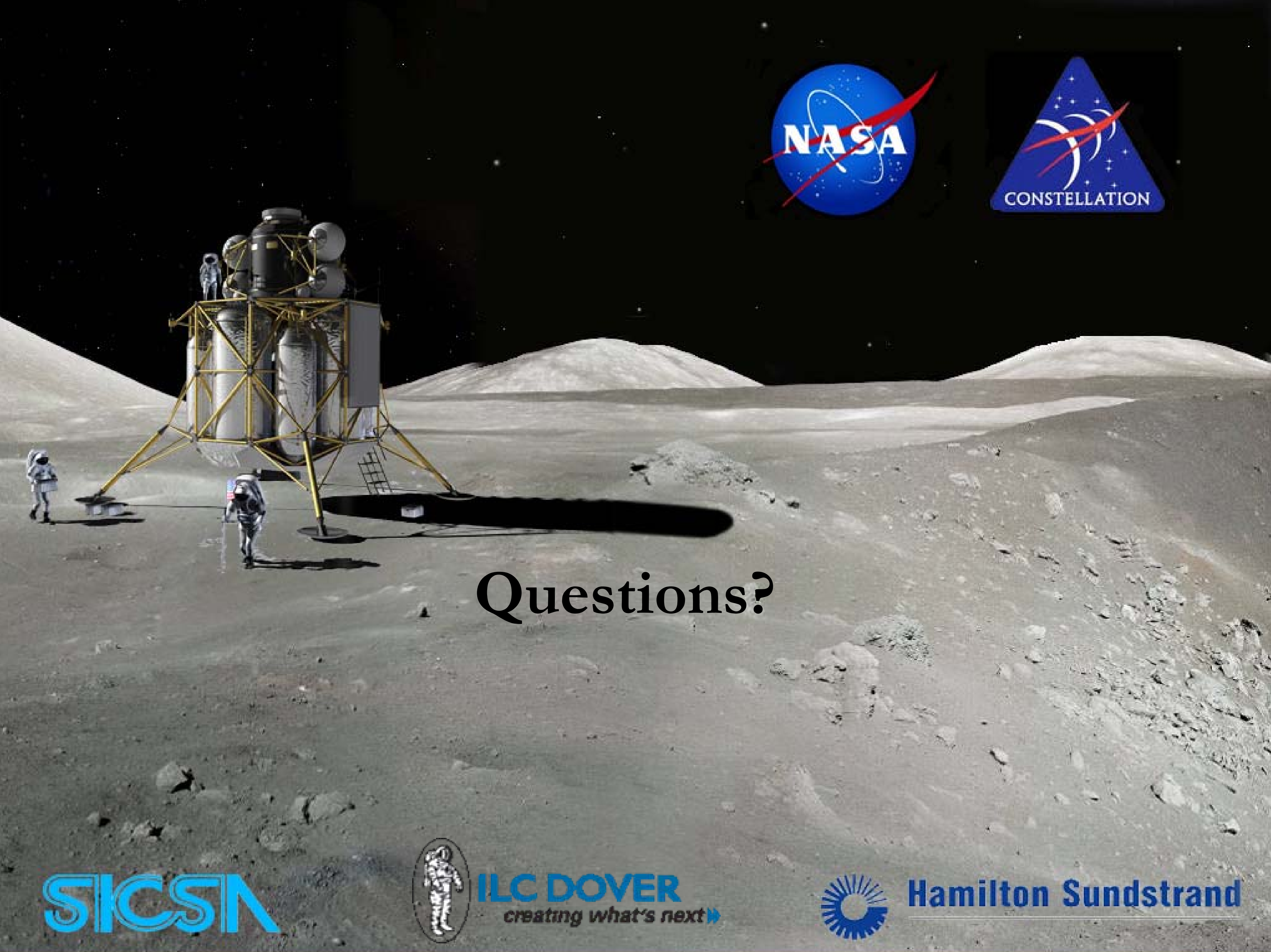
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Questions?
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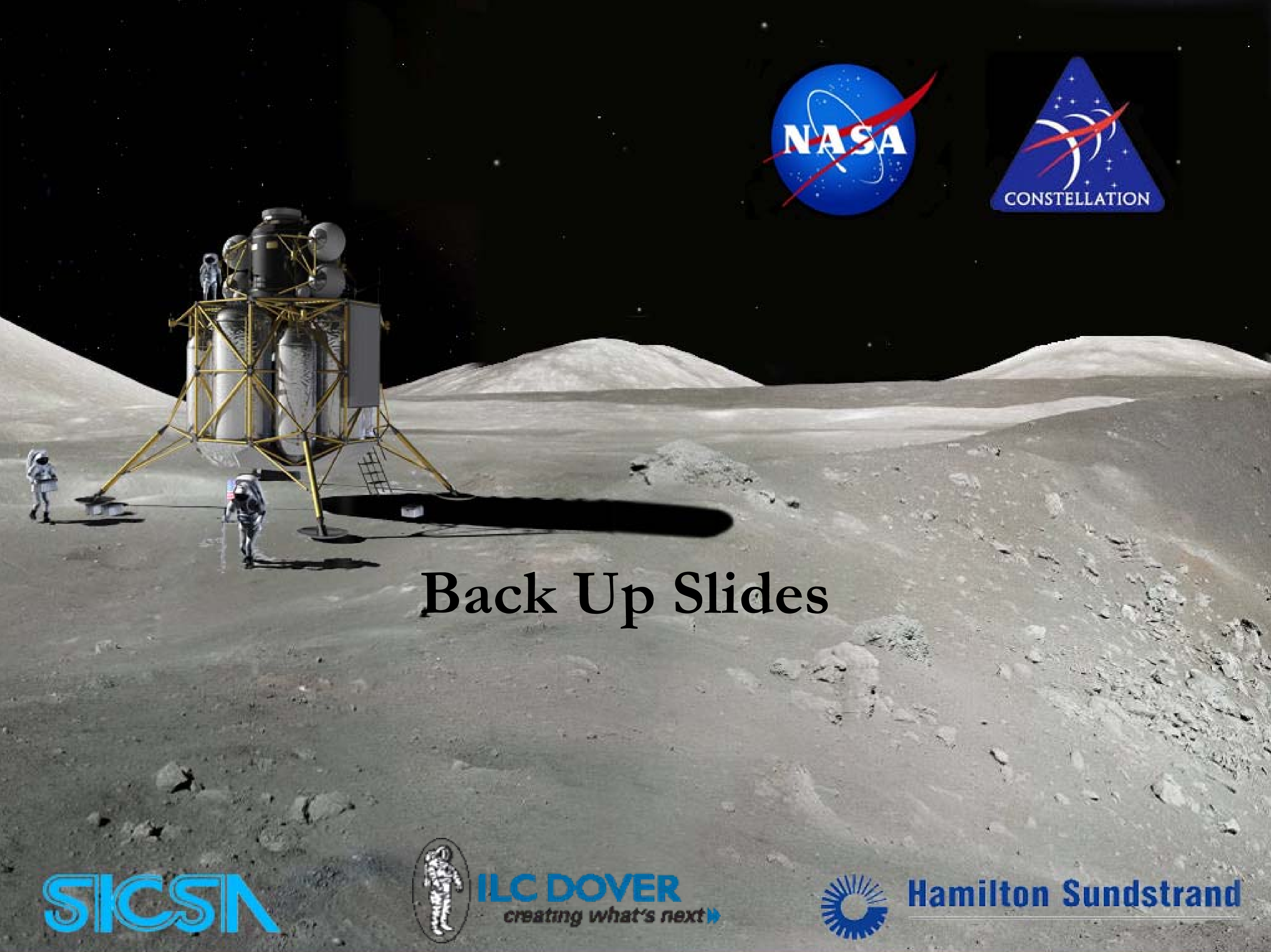
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Back Up Slides
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# Minimum Functions

## Supplies

| Function | Metric | Intra-related | External | Absolute Mininum | Rationale |
|---|---|---|---|---|---|
| *Crew supplies* | | | | | |
| Food | Volume / mass | Storage | | Per person per day | Needed for Survival |
| Water | Volume / mass | tank volume | | Per person per day | Needed for Survival |
| Hygiene items | Volume / mass | Storage | | Per person per day | Crew Health |
| Medical items | Volume / mass | Storage | | Altair med kit | Crew Health |
| Clothing | Volume / mass | Storage | | Min sanitary conditions | Hygiene |
| *Habitat element supplies* | | | | | |
| Habitat element maintenance items | Volume / mass | Living quarters related | | Duration and use | Small capability outweighs not having the capability |
| Habitat tools | Volume / mass | Living quarters related, storage | | Defined by design - none | Multifunctionality dictates changing of common areas |
| EVA suit maintenance, spares and repair items | Volume / mass | Use habitat tool kit | EVA defined | Visors and cover gloves - spares | EVA suit risk, back-up items |

## Power

| Function | Metric | Intra-related | External | Absolute Mininum | Rationale |
|---|---|---|---|---|---|
| Accept power from source | Watts | Interface location | Location of source | By standard design | Needed for operation of habitat |
| Distribute power to habitat items requiring it | Distances, watts | Overall habitat configuration | EVA mission support | No expansion capability in habitat | Needed for operation of habitat functions |
| Manage allocating available power and demands | Available power vs. call for power | | Supply side redundancy transitions if required | No growth within min required | Needed for operation of habitat functions |
| Monitor habitat power | Telemetry; number of points and rate | | Computing and Communications | No growth within min required | Needed for operation of habitat functions |

# Minimum Functions

### *Crew Accommodations*

| Function | Metric | Intra-related | External | Absolute Minimum | Rationale |
|---|---|---|---|---|---|
| *Living* | | | | | |
| Food Prep | Volume / Power | | | No preparation needed | Needed to Survive |
| Sleeping | Area | | | Volume and time allocated for sleeping | Needed to Survive |
| Exercise | | Storage | Medical definition of equipment | Volume for resistance device | Prevent muscle degradation |
| Medical care | | Storage | | Volume for Altair Med Kit | Some limited capability outweighs not having any capability |
| *Working* | | | | | |
| Science equipment | Volume / Power | Isolation | | No requirement for min hab | Reference Mission |
| Habitat monitoring | Volume of data, reporting frequency, data type (sensors) | Sensor placements | Lander communications system interface | Monitor breathable air and pressure | Reference Mission |
| Computing | Speed, data storage, | Power distribution | Lander interface | Operate habitat systems | Implied for Science and hab functions |
| Communications | Rate, distance, links | Within habitat, power distribution | Communications hub, EVA crew | As per BAA only need to define bandwidth | Reference Mission |
| Caution/Warning | data; # points, frequency and rate | Computing | Downlink | Min Computer | Crew Safety |
| Navigation equipment | Volume, power | Power distribution | Antennas | Visual reference | Implied for EVA |



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# Minimum Functions

## *Habitat Environment*

| Function | Metric | Intra-related | External | Absolute Minimum | Rationale |
|---|---|---|---|---|---|
| *Atmosphere composition* | | | | | |
| Total pressure control | kPa | | | Sampling | Maintain internal pressure within design limit |
| O2/N2 ratio | Measured ratio | Monitoring | | 30% O2 +30%/-0%; 20% O2 is near Hypoxia limit at 8psia | Pure 02 health and fire hazard, lean O2 deadly |
| O2 make-up | Loss rate / loss events | EVA events | | 1.8 lbs/day/person + habitat leakage and O2 transfer equipment leakage + EVA suit leakage/losses and airlock cycle losses ~ 8.8 lbs/day for 4 person crew. | O2 consumed via human metabolic processes |
| CO2 removal | PPM rate and total | | | 2.2 lbs/day/person – habitat leakage – EVA suit cycle – airlock cycle losses ~ 7.3 lbs/day for 4 person crew. | CO2 becomes poisonous |
| Humidity control | Humidity measurement and rate change | Water usage / collection | | Target 25-75% RH | High humidity accelerates mold growth, corrosion, etc.; Low humidity irritates human respiratory system, increases electro-static problems |
| Trace Contaminate Control | Measured | Dust mitigation methods in in-situ protection | # of entry sources | Many substances, including Methane and other volatile organics, aromatic hydrocarbons, potentially CO and H2 | Trace contaminants represent human health hazard and potentially fire hazard |
| Temperature | Degrees F | Power required / rejected | Solar and deep space radiation | Target 65-85 Deg F average temperature | Provide shirtsleeve comfort for improved work efficiency and reduced fatigue |
| Circulation / ventilation | Changes per hour | | Habitat hot-side or cold-side | Habitat thermal design may result in adequate passive convective flow | 1/6 g may be inadequate to prevent stagnation around crew for O2/CO2; may result in inadequate thermal comfort, may result in inadequate cooling of equipment |

# Minimum Functions

## *Habitat Environment continued*

| | | | | | |
|---|---|---|---|---|---|
| *Potable Water* | | | | | |
| Water distribution | Gallons / time | | | TBD – varies with habitat architecture and layout | Provide for crew health |
| Reuse | Gallons / person /day | Storage volume | | Reclamation of 90% (excluding EVA cooling losses) trades 15-21 day time frame with "guesstimated" PWV of equipment. Technology improvements, or integration of "still" into habitat could reduce power/weight/volume of reclamation equipment, improving timeline of trade point for reclamation. | Reduce Earth up mass and reduce storage requirements |
| Purification | Gallons/hour | Post usage sources | | Needed only if reuse becomes baseline. | Necessary for human health |
| Monitoring | Quality | | | Needed only if reuse becomes baseline. | Necessary for human health |
| *Human Waste Mgmt* | | | | | |
| Processing | hr/person/day | Storage volume | | Storage | Necessary for crew work efficiency and human health |
| Collection | Power/volume/ equipment required | Power | | Original Apollo system (bags/wipes); "camp" toilet provides improved performance at minimal weight/volume. | Necessary to support human bodily functions |

# Function / Subsystem Concepts

**Environmental**
- MMSE
- Thermal
- Radiation
- Dust

**Habitat Environment**
- ECLSS
- Water
- Waste
- Food Preparation
- Hygiene
- Consumables

**Habitat Operations**
- Monitoring
- Storage
- Sleeping
- Power and Lighting
- Ingress/Egress
- EVA Operations

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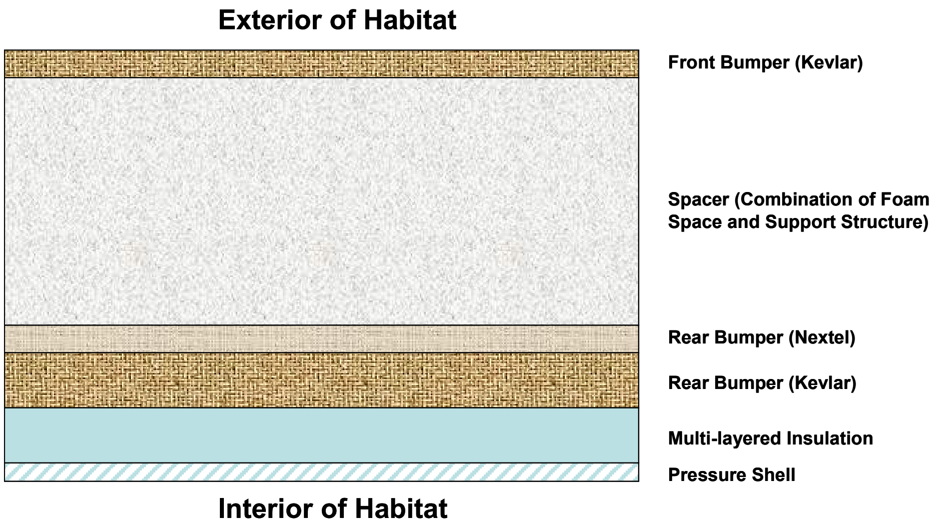
# MMSE Protection Study

- Meteoroids and Micrometeoroids
  - Cometary and asteroidal sources
  - Periodic (i.e. nearly identical orbits) or sporadic (i.e. random orbits)
  - Average mass density and mean speed of meteoroids and micrometeoroids are approx. 0.5 g/cm$^3$ and 30 km/s
  - Objects traveling at such speed can pose a serious threat to the habitat on the lunar surface. [i]
- Secondary Ejecta
  - Particles ejected from meteoroid impact and landing and take off events.
  - Lunar ejecta caused by meteoroid impact have an estimated average mass density of 2.5 g/cm$^3$ and mean velocity of 0.1 km/s.



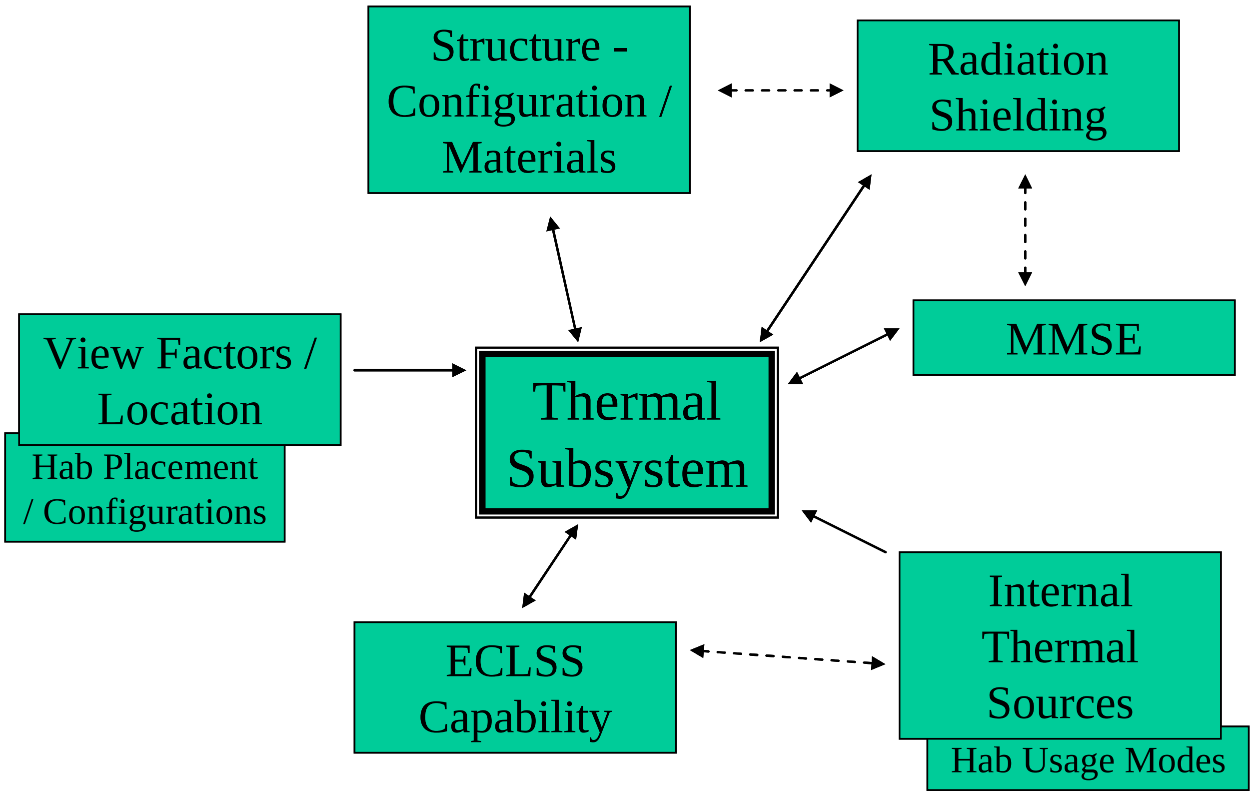

Shield Design: Kevlar composite front bumper with a minimum thickness of 0.25 cm (0.1 in), Nextel and Kevlar rear bumper with 0.30 cm (0.12 in) and 0.64 cm (0.25 in) respective thickness, and the spacing between the front and rear bumpers at approximately 10 cm (3.94 in) or greater

| Description | Material | Area Density |
|---|---|---|
| Front Bumper | Kevlar Composite fabric 0.25 cm thick - 5 layers of 300 g/m2 Kevlar fabric | 1.5 kg/m$^2$ |
| Rear Bumper | Nextel 0.30 cm thick | 2.8 kg/m$^2$ |
| | Kevlar 0.64 cm thick | 4.0 kg/m$^2$ |
| Spacer | | 1.7 kg/m$^2$ |
| **Total** | | **10 kg/m$^2$** |

[i] Rais-Rohani, M., "On Structural Design of a Mobile Lunar Habitat With Multi-Layered Environmental Shielding," NASA/CR-2005-213845, pp. 8-10, Mississippi State University, April 2005, Mississippi

# Thermal Design

- Habitat thermal design consideration and interactions
  - Multiple influences on habitat thermal condition



# Thermal Design

- Categories of thermal extremes
  - Crew comfort
    - Temperature range; 18ºC to 28ºC
  - Equipment
    - Temperature range; 0ºC to 40ºC
  - Structure
    - Temperature range; -45ºC to 65ºC

  - The internal temperature driver is the crew comfort. While the habitat is unoccupied the range may be allowed to go to the equipment extremes.
  - The structure would be under the insulation and close to the interior temperature.
  - The ECLSS section will cover the thermal control subsystem

# Thermal Design

- Significant driver of the habitat thermal conditions are the lunar solar / vacuum environment and acceptable habitat temperature range
  - Habitat insulation deemed required vs. interior system overcoming the lunar environment un-insulated result
  - Options for insulating/managing environment were traded

| Criteria / Approach | Mass | Deployment / Maintenance | Complexity / reliability | Adaptibility | Packed Volume | Other Impacts | | |
|---|---|---|---|---|---|---|---|---|
| *Weighting Factor* | *0.8* | *0.9* | *0.6* | *0.9* | *0.5* | *0.7* | Total ↓ | Rank ↓ |
| **MLI** | 7 | 10 | 10 | 9 | 8 | 10 | 39.7 | 1 |
| **Panels** | 5 | 9 | 7 | 8 | 7 | 9 | 33.3 | 2 |
| **Regolith** | 10 | 1 | 9 | 2 | 10 | 1 | 21.8 | 3 |

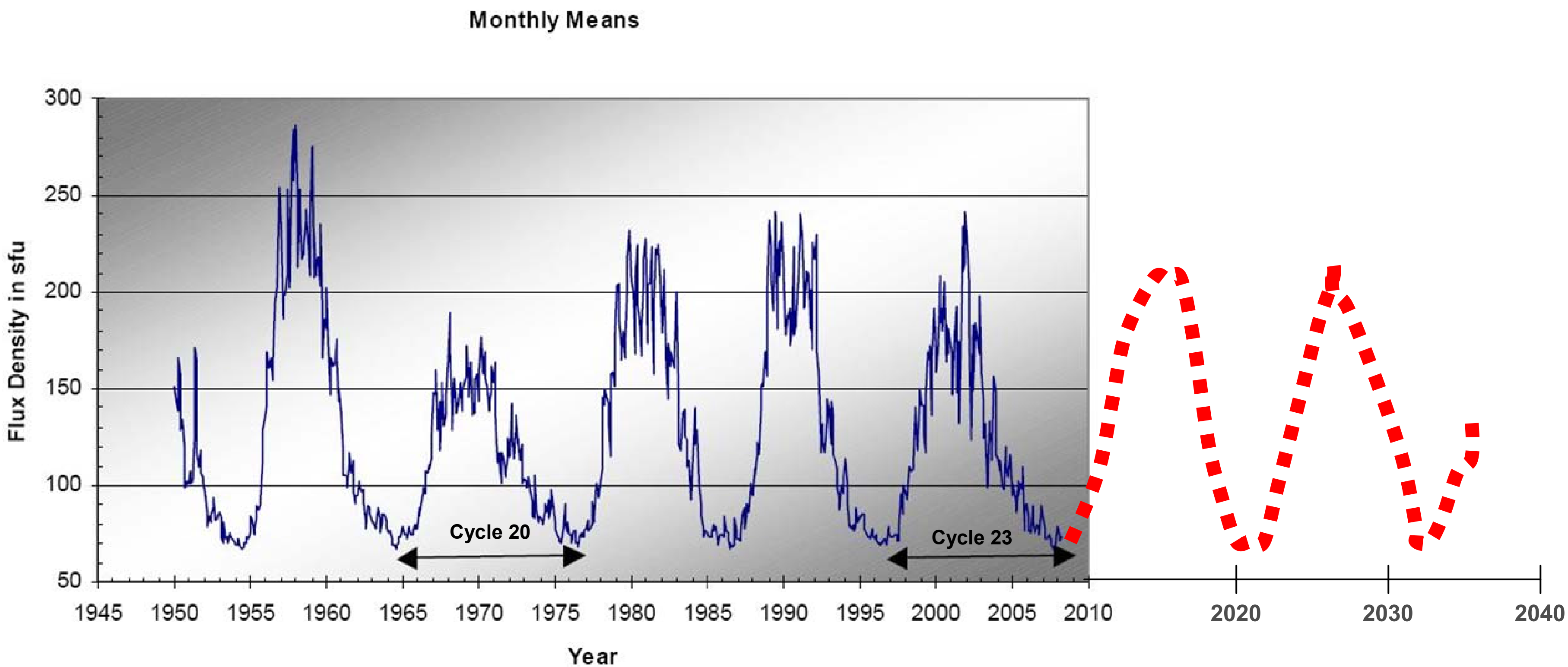
*Weighting 1 = criteria is major design driver, to 0.1 = less of selection influence*
Score 10 = good solution for given criteria, to 1 = bad solution for given criteria
Total is the sum of the weighting times the score for each criteria for an approach

# Radiation Protection Study

| Dose limits for short-term or career non-cancer effects (in mGy-Eq. or mGy) | | | |
|---|---|---|---|
| ***Organ*** | ***30 Day Limit (mGy-Eq)*** | ***1 Year Limit (mGy-Eq)*** | ***Career Limit (mGy-Eq)*** |
| **Lens*** | 1000 | 2000 | 4000 |
| **Skin** | 1500 | 3000 | 4000 |
| **BFO** | 250 | 500 | Not Applicable |
| **Heart**** | 250 | 500 | 1000 |
| **CNS***** | 500 | 1000 | 1500 |
| **CNS*** (Z ≥ 10)** | | 100 (mGy) | 250 (mGy) |

*Lens limits are intended to prevent early (< 5 yr) severe cataracts (e.g., from a solar particle event). An additional cataract risk exists at lower doses from cosmic rays for sub-clinical cataracts, which may progress to severe types after long latency (> 5 yr) and are not preventable by existing mitigation measures; however, they are deemed an acceptable risk to the program.
** Heart does calculated as average over heart muscle and adjacent arteries.
*** Central Nervous System (CNS) limits should be calculated at the hippocampus.

# Radiation Protection Study




- The reference mission provided by NASA has a 10 year timeline from 2019 to 2029.
- 2008 is a transition year between cycle 23 and cycle 24 and the Sun's activity is currently at a minimum.
- 2019 will most likely be the end of the current cycle or the beginning of the next cycle.
- There is a high probability of SPE in the middle of the reference mission as the Sun moves toward maximum solar activity in Solar Cycle 25.
- Habitat element should be designed for an SPE event level.

# Radiation Protection Study

| Organ | Aluminum Shield Thickness for Solar Flare Event | | | | | |
|---|---|---|---|---|---|---|
| | *February 1956* | | *November 1960* | | *August 1972* | |
| | $g/cm^2$ | cm | $g/cm^2$ | cm | $g/cm^2$ | cm |
| Skin | 1.3 | 0.5 | 2.5 | 1.0 | 7.5 | 2.8 |
| Eye | 1.5 | 0.6 | 3.5 | 1.3 | 9.5 | 3.5 |
| BFO | 24.0 | 8.9 | 22.0 | 8.1 | 18.0 | 6.7 |

**Effective Dose Based on 1972 Solar Particle Event**

| Shielding (Aluminum) | | | Effective Dose (E) (mGy-Eq) | Average BFO Dose Equivalent ($H_T$) (mGy-Eq) |
|---|---|---|---|---|
| Area Density ($g/cm^2$) | Equivalent Thickness (cm) | Equivalent Thickness (in) | | |
| 1 | 0.370 | 0.146 | 3375 | 1110 |
| 5 | 1.852 | 0.729 | 885 | 563 |
| 10 | 3.704 | 1.458 | 402 | 305 |

This Solar Particle Event occurred between Apollo 16 and Apollo 17

Effective dose, $E = \Sigma w_T H_T$ ,is a weighted average of dose equivalent to various organ and/or tissue types

# Radiation Protection Study

| Annual GCR Doses (Deep Space), 1977 Solar Minimum | | | | | | | |
|---|---|---|---|---|---|---|---|
| Shielding (Aluminum) | | | Skin | | Bone Marrow | | |
| Area Density ($g/cm^2$) | Equivalent Thickness (cm) | Equivalent Thickness (in) | Annual Dose (mGy) | Annual Dose Eq (mGy-EQ) | Annual Dose (mGy) | Annual Dose Eq (mGy-Eq) | Annual Effective Dose (mGy-Eq) |
| 1 | 0.370 | 0.146 | 184 | 798 | 164 | 445 | 488 |
| 5 | 1.852 | 0.729 | 183 | 669 | 163 | 405 | 437 |
| 10 | 3.704 | 1.458 | 180 | 562 | 161 | 370 | 393 |

On the Lunar Surface, Organ Doses and Dose Equivalents are about half those in deep space

- The skin shell concepts of the current crew exploration vehicle (CEV) are 5.0 to 7.0 mm 7050-T73651 aluminum alloy with ribs, frames, isogrid skin or uniform skin options. [i] If the habitat skin shell design follows the CEV design (i.e. using 5.0 to 7.0 mm aluminum skin), no additional shielding will be required to protect the crew from GCR particularly for short duration missions such as the current reference mission.
-

[i] Mukhopadhyay, V., “Structural Configuration Analysis of Crew Exploration Vehicle Concepts,” AIAA 2006-2082, 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, May 1-4, 2006, Newport, RI

# Radiation Protection Trade Study

| Approach \ Criteria | Mass | Material Compatibility | Deployment / Maintenance | Complexity / reliability | Adaptibility | Packed Volume | Other Impacts | Total | Rank |
|---|---|---|---|---|---|---|---|---|---|
| *Weighting Factor* | *1* | *0.7* | *0.8* | *0.9* | *0.7* | *0.8* | *0.6* | **Total** | **Rank** |
| **Regolith Shell (Bulk, Exterior, ~ 1.5" thick)** | 10 | 7 | 3 | 10 | 5 | 10 | 1 | 38.4 | 3 |
| **Regolith Wall (Local, Internal, ~ 1.5" thick)** | 9 | 7 | 5 | 8 | 7 | 10 | 3 | 39.8 | 1 |
| **Regolith Blanket (Local, Internal, Reconfigurable, ~ 1.5" thick)** | 8 | 7 | 7 | 6 | 8 | 10 | 3 | 39.3 | 2 |
| **Water Storage/Wall (Internal, Permanent, made from hydrogenated materials, ~ 4" thick)** | 7 | 6 | 5 | 5 | 5 | 10 | 5 | 34.2 | 7 |
| **Deployable Water Wall (Interior, made from polyethylene, ~ 4" thick)** | 7 | 6 | 4 | 4 | 8 | 9 | 4 | 33.2 | 8 |
| **Polyethylene Brick Wall (Internal, ~4" thick)** | 2 | 8 | 8 | 10 | 6 | 3 | 8 | 34.4 | 6 |
| **Polyethylene Blanket (Internal, Deployable, Reconfigurable, 0.5 to 1" thick, used in combination with other approaches)** | 3 | 8 | 7 | 9 | 9 | 6 | 7 | 37.6 | 4 |
| **Personal Vest (Combined Materials, 0.5" thick, used in combination with other approaches)** | 4 | 8 | 8 | 9 | 5 | 5 | 9 | 37 | 5 |

# Radiation Protection Solution

- Long Term vs. Short Term Solution
  - How much shield do we need?
    - Dose equivalent on the lunar surface = half of deep space.
    - SPE protection require 10 to 12 g/cm$^2$ of aluminum shield (Equivalent).
  - Shielding Material Options
    - **Lunar Regolith** - Similar area density as aluminum, the mean molecular weight of the lunar regolith is comparable with the atomic weight of aluminum [Simonsen, based on Apollo returned samples].
    - **Liquid hydrogen** - The most efficient shielding material
    - **Water** – Relatively efficient
    - **Lithium hydride** – Similar to water
    - **Polyethylene** – 30% more efficient than aluminum [i]
    - **Aluminum** - Poor shielding material due to the hazard of secondary radiations. Need large thickness to be effective
    - **Materials with higher atomic numbers than aluminum** – Similar problem as aluminum
    - **Hydrogenated graphite nanofibers with herringbone structure (HGNF)** - potentially 4 to 6 times more efficient than aluminum in protecting astronauts [ii]

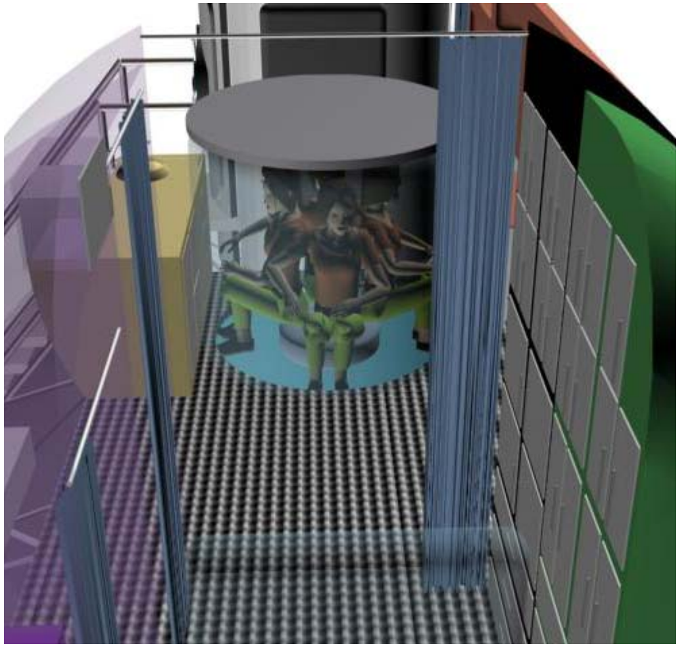
- [i] Space Radiation, Part 2: Learning from Experiments in Space, Space Life Sciences Research Highlights, Office of Biological and Physical Research, NASA, October 2003.
- [ii] Tripathi, Ram K., Nealy, John E., “Mars Radiation Risk Assessment and Shielding Design for Long-Term Exposure to Ionizing Space Radiation,” IEEEAC paper #1291, Version 4, November 23, 2007

# Radiation Protection Solution

- Long Term Approach
  - Lunar regolith is the most efficient long term approach
    - The use of emergency underground SPE storm shelter
    - Regolith filled shield on mobile units
  - The next approach is to use reconfigurable polyethylene blanket.
    - Will keep the dose rate low in everyday use.
    - Create (or configure into) a storm shelter for a solar particle event
    - Applying this approach to a four-person sleeping quarter doubled as SPE storm shelter that is 7 ft [2.13 m] long by 7 ft high by 6 ft [1.82 m] wide, covering all surfaces, would result in a subsystem mass of approximately 3000 kg. Practical if assembled over some period of time.
  - Use plastic (like polyethylene) wherever possible (ALARA)
    - Transportation containers (bags, boxes, etc.)
    - Furniture, equipment box, workstation, etc.
    - Make them reconfigurable for multi-use

# Radiation Protection Solutions

- Short Term Approach
  - Regolith approaches cannot be affectively implemented in short term due to other infrastructure impacts
  - Reconfigurable polyethylene blanket SPE storm shelter is difficult to achieve in short term
  - Another approach is to use water, but that would require the habitat to maintain sufficient amount of water and equipment to deploy the temporary shelter (wall, mattress or tube). The amount of water required to provide coverage for four people will be approximately 2000 kg and the associated equipment (assuming gravity fill) will be roughly 200 kg.
  - The use of water can also be an effective long term approach



# Dust Mitigation

- Minimize dust into habitat for health and equipment performance reasons
- Airlock is multi-functional
- Operations description has more detail

## IVA Ops

Containment in vehicle for handling of dusty components


## Staging Ops

Air lock and/or protective enclosure are stage areas to don/doff covers and prevent dust migration to habitat

Elevated Grating - dust drops to surface off boots

## EVA Ops

Concealment of critical areas

# Function / Subsystem Concepts

**Environmental**
- MMSE
- Thermal
- Radiation
- Dust

**Habitat Environment**
- ECLSS
- Water
- Waste
- Food Preparation
- Hygiene
- Consumables

**Habitat Operations**
- Monitoring
- Storage
- Sleeping
- Power and Lighting
- Ingress/Egress
- EVA Operations

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# ECLSS

- Focus on innovative multi-function materials and use of inflatables
- Baseline - 8 psia, 30% $O_2$, pp$CO_2$ < 3.8 mmHg, No $H_2O$ recovery, waste stored in bags (e.g. pack in - pack out camping toilet), Rapid Cycle Amine system for $CO_2$ removal (Orion), $O_2$ stored in high pressure tanks on site, dry and wet food, Wipes (wet and dry) for all hygiene except water/toothpaste/basin for oral hygiene, no clothes wash (maybe vacuum bakeout)
- Reuse of two PLSSs for $CO_2$ removal
- Habitat thermal treatment designed for 1500 watts heat rejection under nominal conditions
- Inflatable thermal chimney instead of radiator

# ECLSS Systems

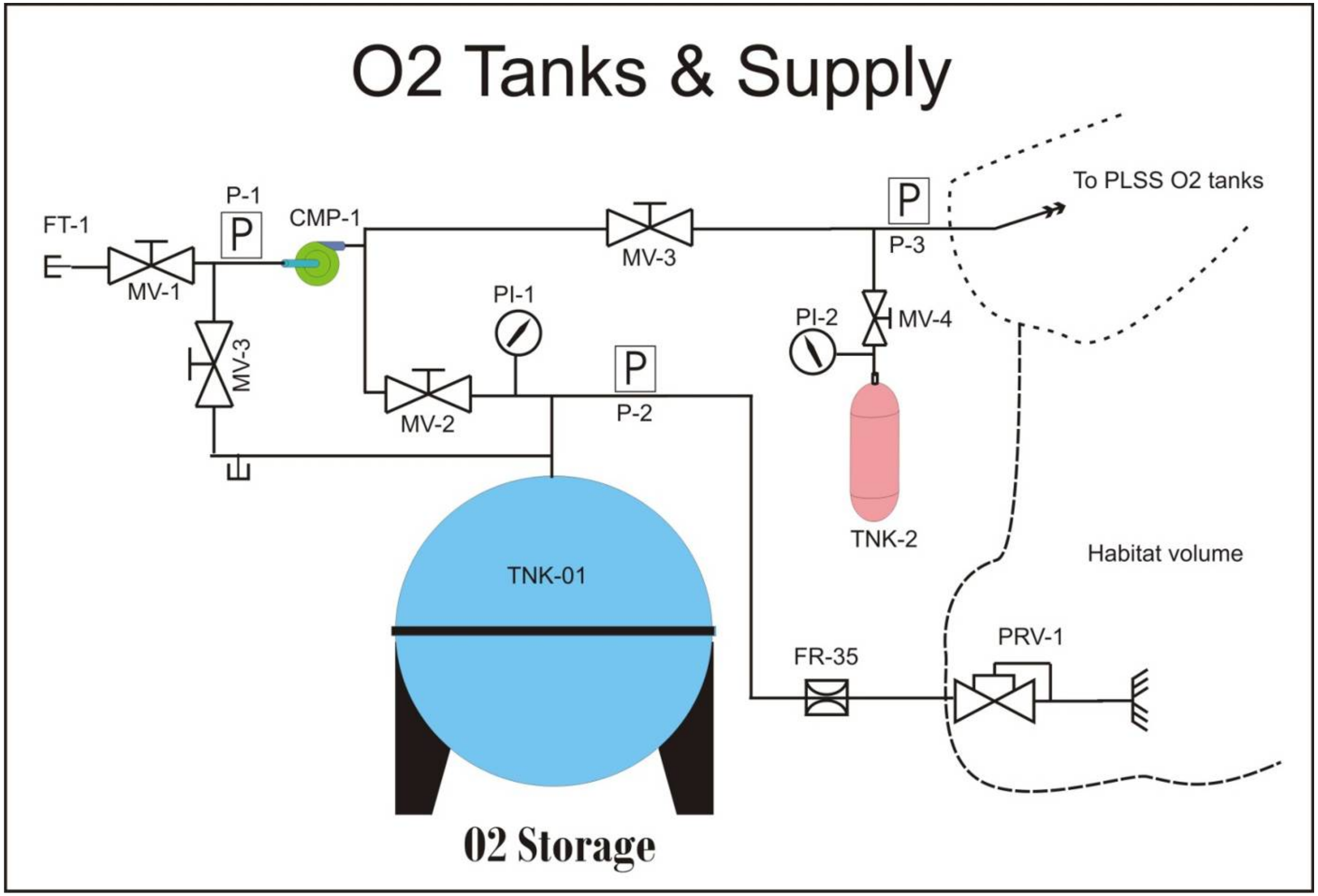
- $O_2$ supply and pressure control
- $N_2$ supply and $O_2/N_2$ ratio mixture control
- Habitat thermal control
- Constituent Gas, Pressure, Temperature Monitor
- Initial Habitat deployment/self health management
- $CO_2$ removal
- Trace Contaminant Control and airborne dust removal
- Potable $H_2O$ Storage and Supply
- EVA Recharge and Supply - $H_2O$, $O_2$, Power
- Airlock Pressure Management and gas recovery
- Food Management
- Hygiene Management
- Waste Collection, stabilization and storage
- Caution and Warning
- Power distribution and lighting

# ECLSS Pressurization

- N2 added to provide 69.5% constant by volume to makeup leakage, air lock cycle, and RCA cycle losses.
- O2 added to maintain pressure to makeup metabolic consumption, and same losses as N2
- Baseline assumes 6 month delay between visits
- O2 for EVA supplied from EVA holding tank maintained at nominal 4000 psia from O2 Main tank pressurized by small transfer pump
- O2 & N2 initial shipment by high pressure tankage
- O2 resupply from LOX, use compressor to maintain pressure tank
- N2 resupply from small replaceable tanks
- Mass Spec Monitor for main gas constituents.

# ECLSS Pressurization

- O2 tank used to maintain pressure



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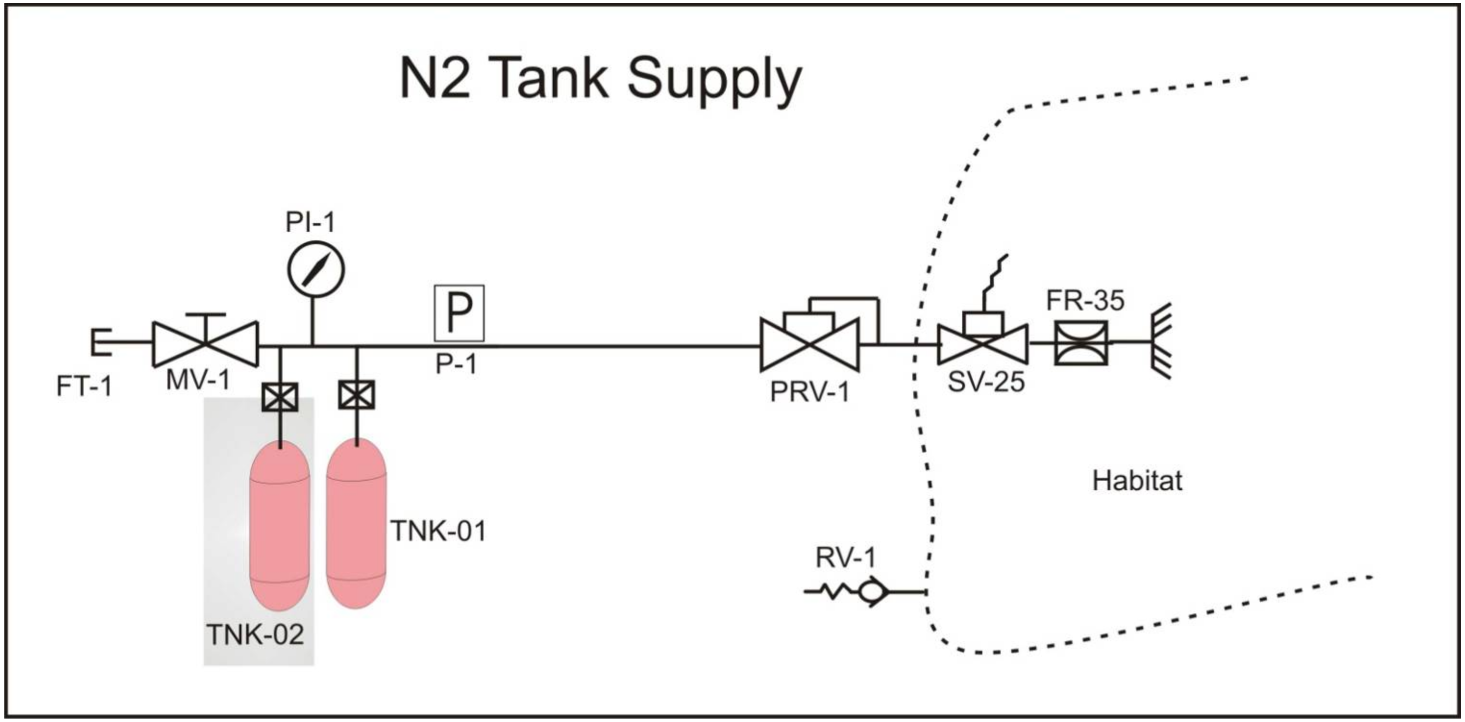
# ECLSS Pressurization

- N2 feed from Atmospheric monitor to maintain ratio
- Habitat relief valve needed during launch to prevent over pressurization of Habitat



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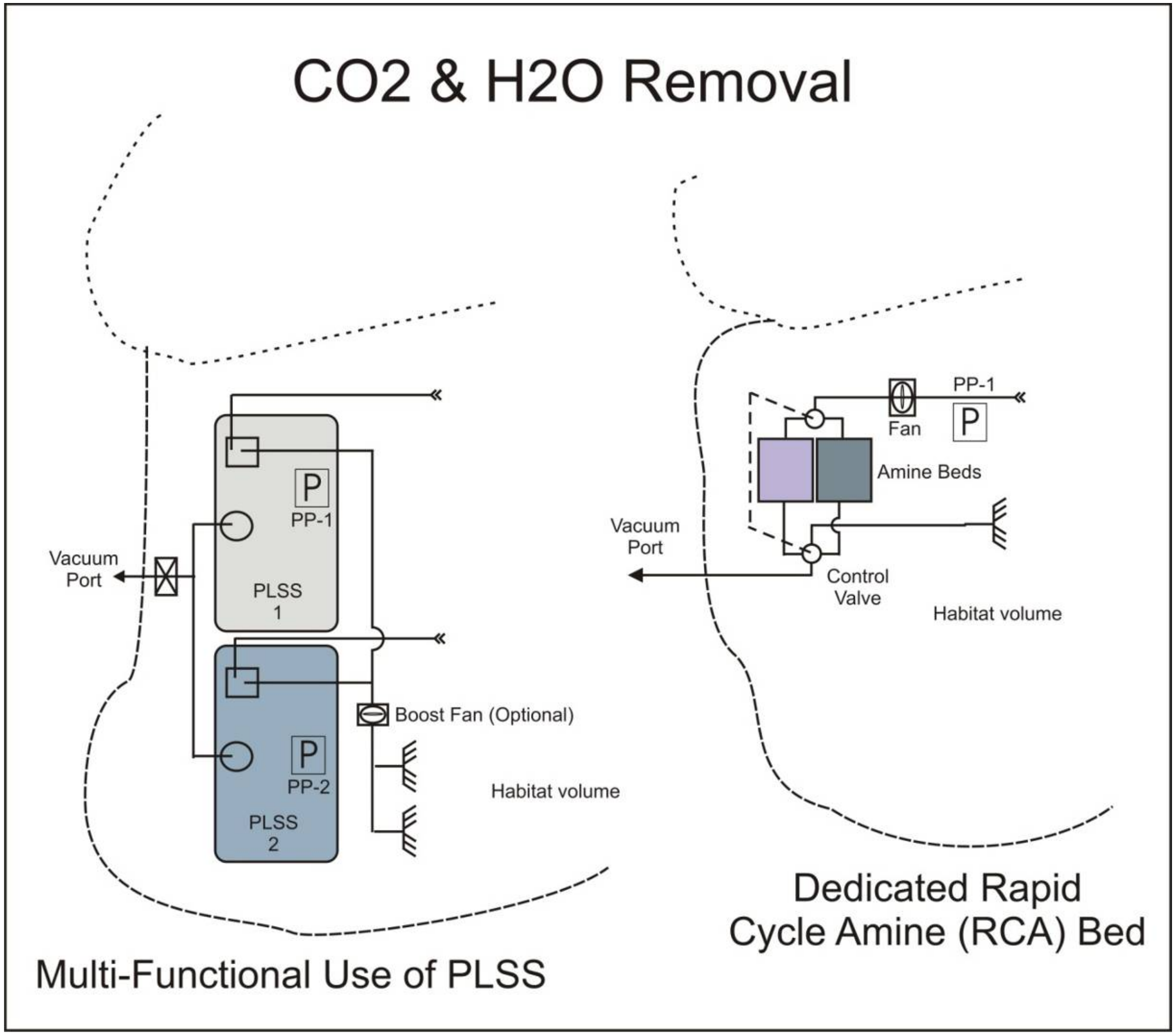
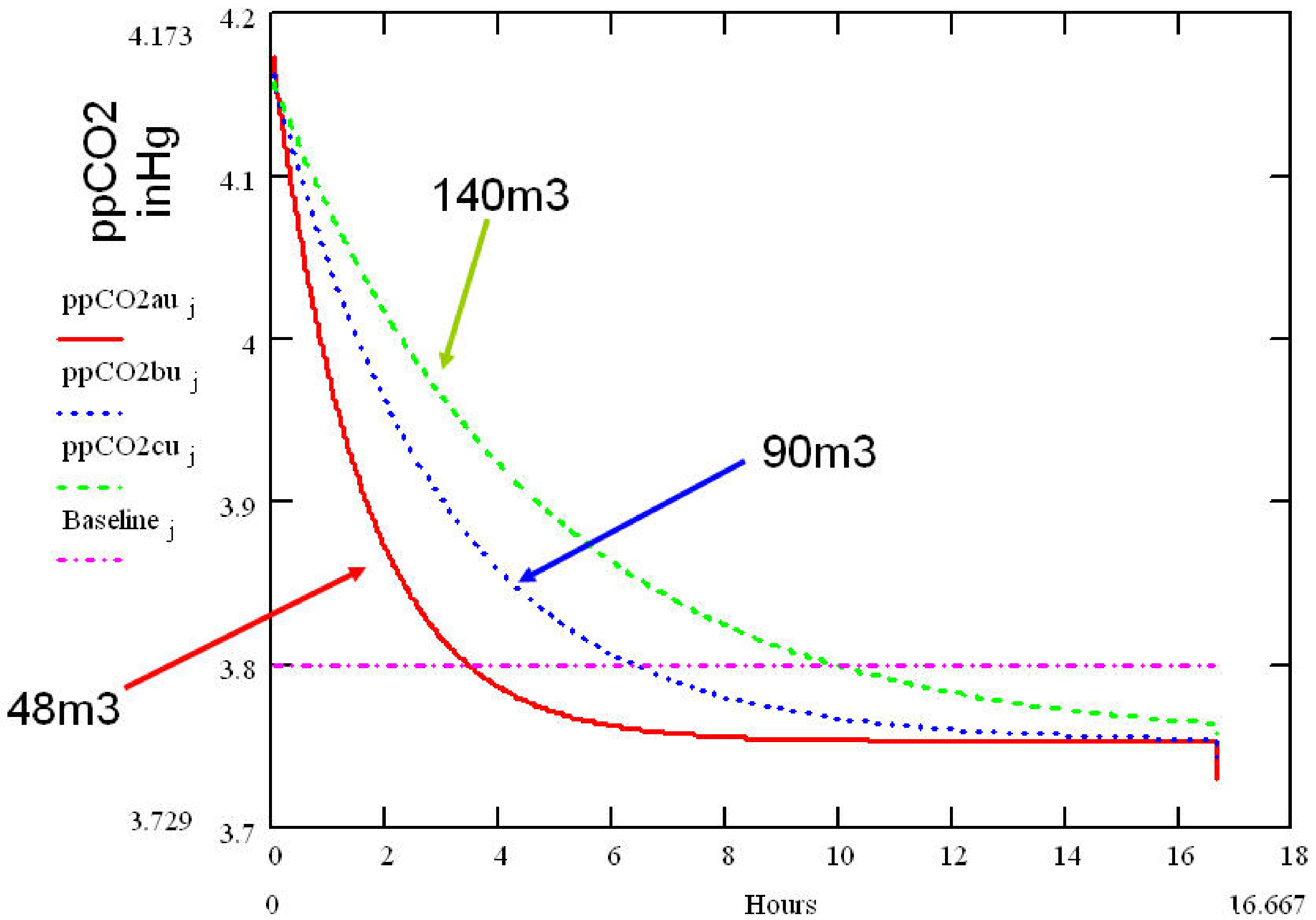
# ECLSS Pressurization

- Recommendation to use Idle PLSSs (2) during crewed operation
- Alternative is dedicated RCA
- PLSS also provides Communications, Control, and CO2 sensing
- Need to provide power and optional "boost fan" if Multi-speed Fan not part of PLSS design



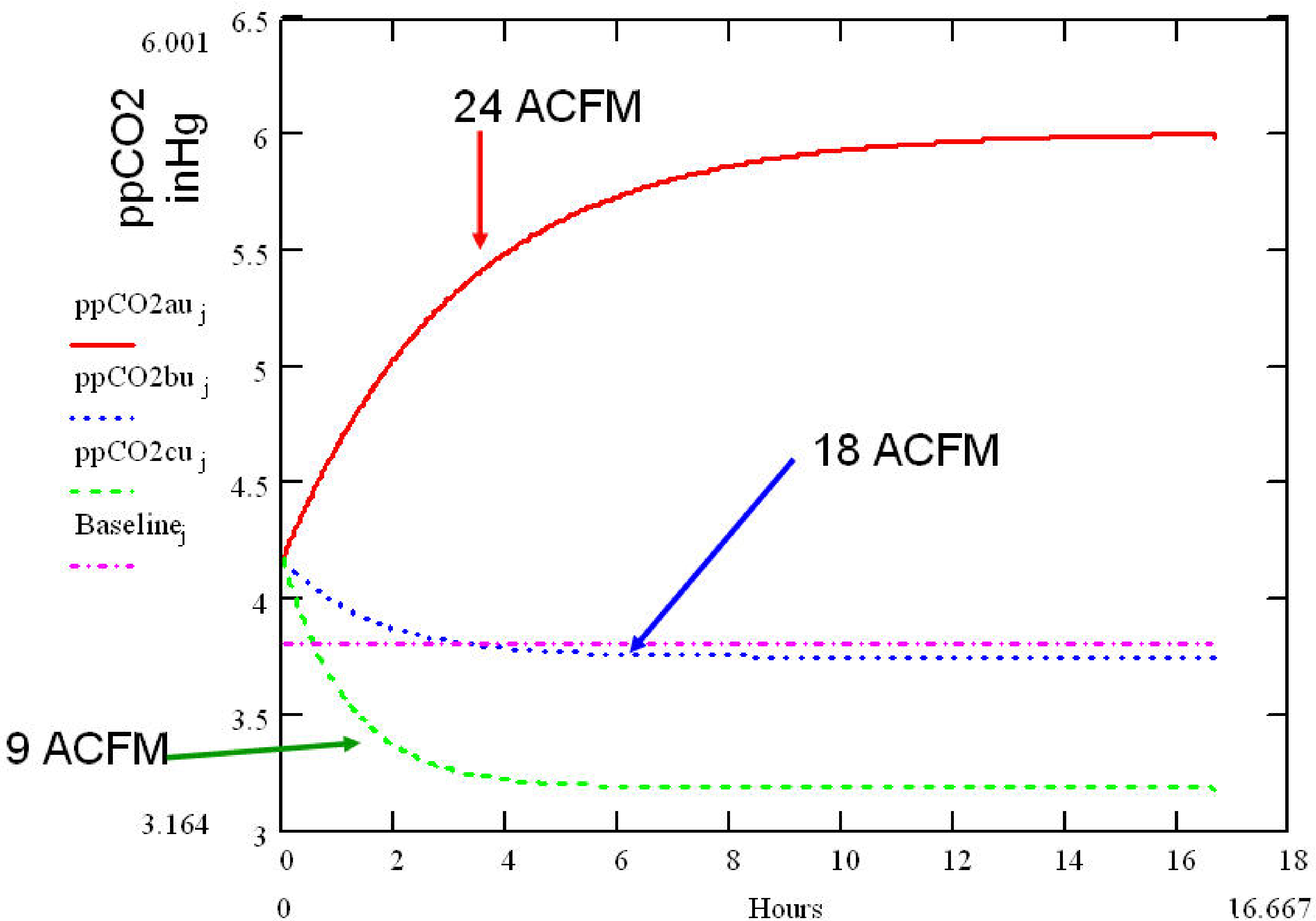
# ECLSS CO2 & Humidity Control

- 2 PLSSs at 9 ACFM each provide ppCO2 < 3.8 mmHg, regardless of volume



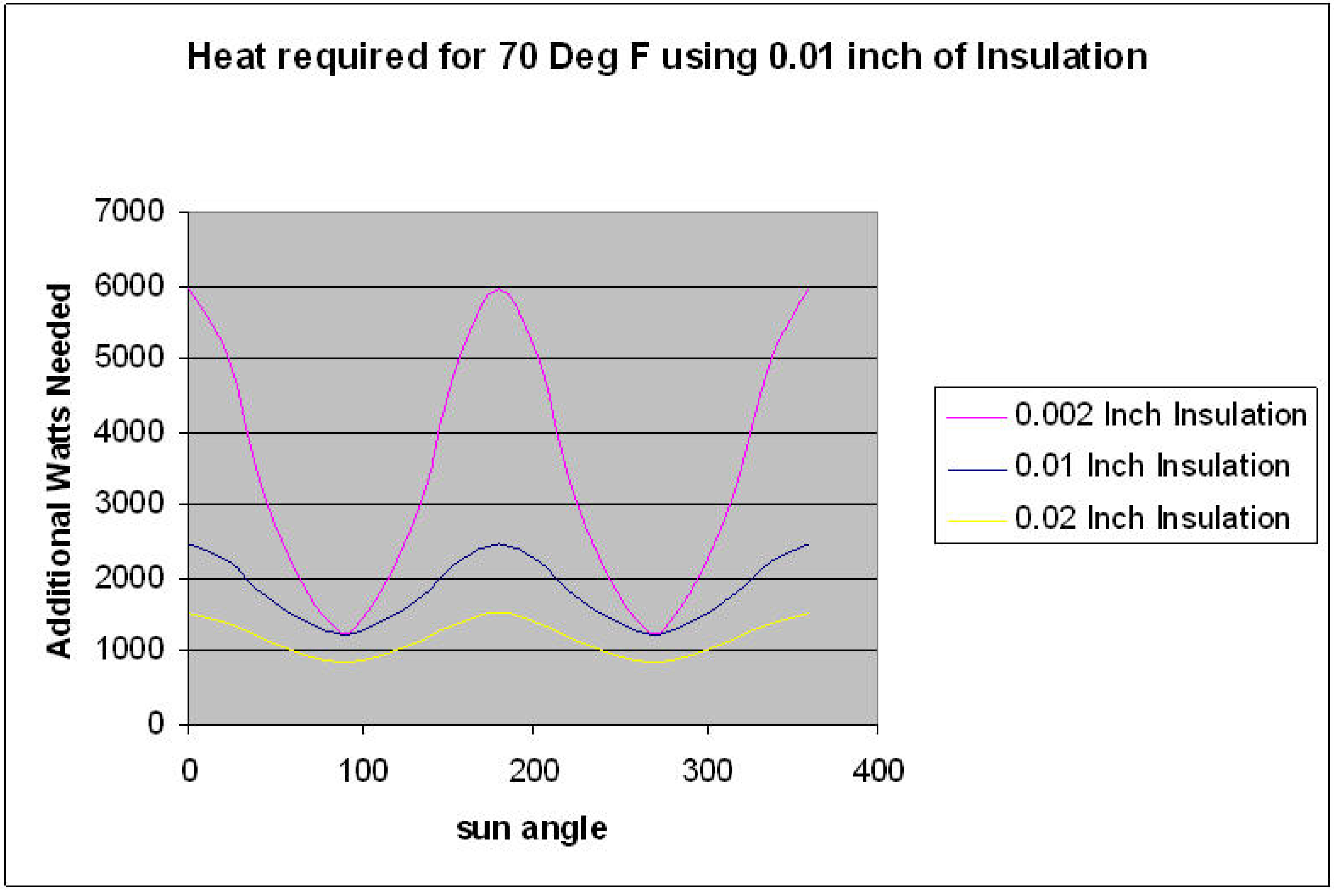
# ECLSS CO2 & Humidity Control

- RCA Flow Rate (and crew CO2 output) determine habitat Steady State ppCO2 level



# ECLSS Thermal Control

- Habitat designed to reject heat
- Thermal chimney provides cooling and heating



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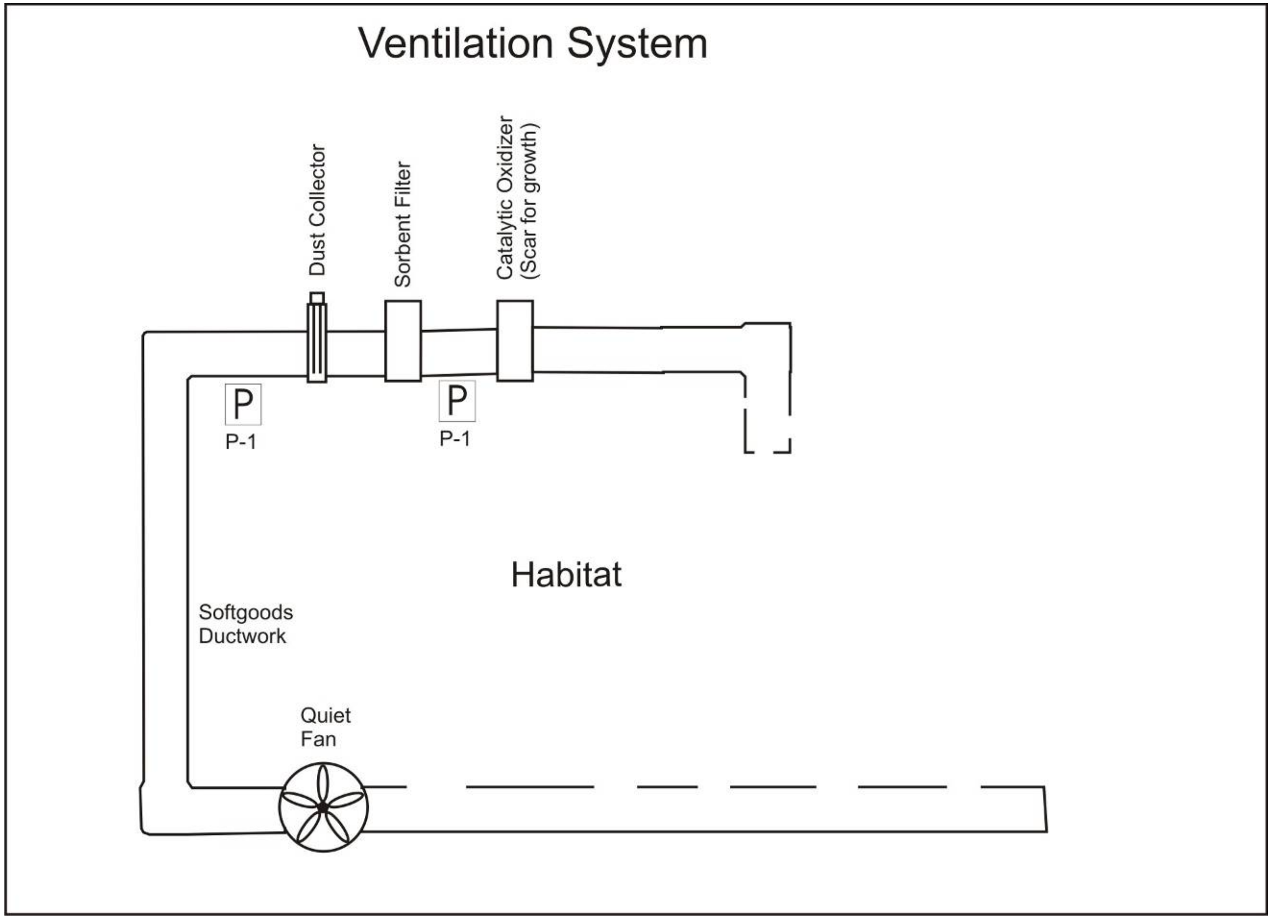
# ECLSS Dust and TCC

- Separate fan for dust and TCC
- Fan also provides air distribution for thermal comfort and air mixing in 1/6 g
- TCC provides odor control, Methane removal, etc.
- TCC for MFHE is replaceable cartridge until second cargo unit
- For “growth”, TCC replaced with regenerative system and catalytic oxidizer to remove methane buildup
- Buildup of methane prior to 4 (TBC) mission remains well below explosive limit

# Ventilation

- Lunar 1/6 g requires forced air ventilation
- Use vent fan for dust, TCC (Sorbent) and Catalytic Oxidizer (added in growth state)
- Use fabric ductwork



# Water Usage

- Water needed for drinking, oral hygiene, and EVA. Water also provided in food
- Water may be needed for human comfort - humidity improvement
- Other uses may include science, additional hygiene, cleansing of food preparation items, etc.

| Water Usage | | | | | |
|---|---|---|---|---|---|
| | kg/P/day | lb/P/day | kg/Mission | lb/M | kg/Mission |
| Metabolic | 2.73 | 6.01 | 305.76 | 672.67 | |
| Water in Food if wet food | 1.15 | 2.53 | 128.80 | 283.36 | |
| Oral Hygiene | 0.36 | 0.79 | 40.32 | 88.70 | |
| | kg/P/EVA | | | | |
| EVA Consumption * | 2.10 | | 58.80 | 129.36 | |
| #EVAs | 28 | | | | |
| * NASA Directive | | | | | |
| EVA Consump - HS | 2.53 | | 70.83 | 155.822 | |
| HS - 530 BTU/hr Metabolic, 50 watts electrical , 85% Eff, leak 130 BTU | | | | | |
| | | | | | |
| Habitat RCA (2 PLSS) loss (assumes 41F dew point | 4.25 | kg/day | Total Water Required | Wet Food | 404.88 |
| Water in air from Metabolic Resiration and evaporation | 9.12 | kg/day | | Dry Food | 533.68 |



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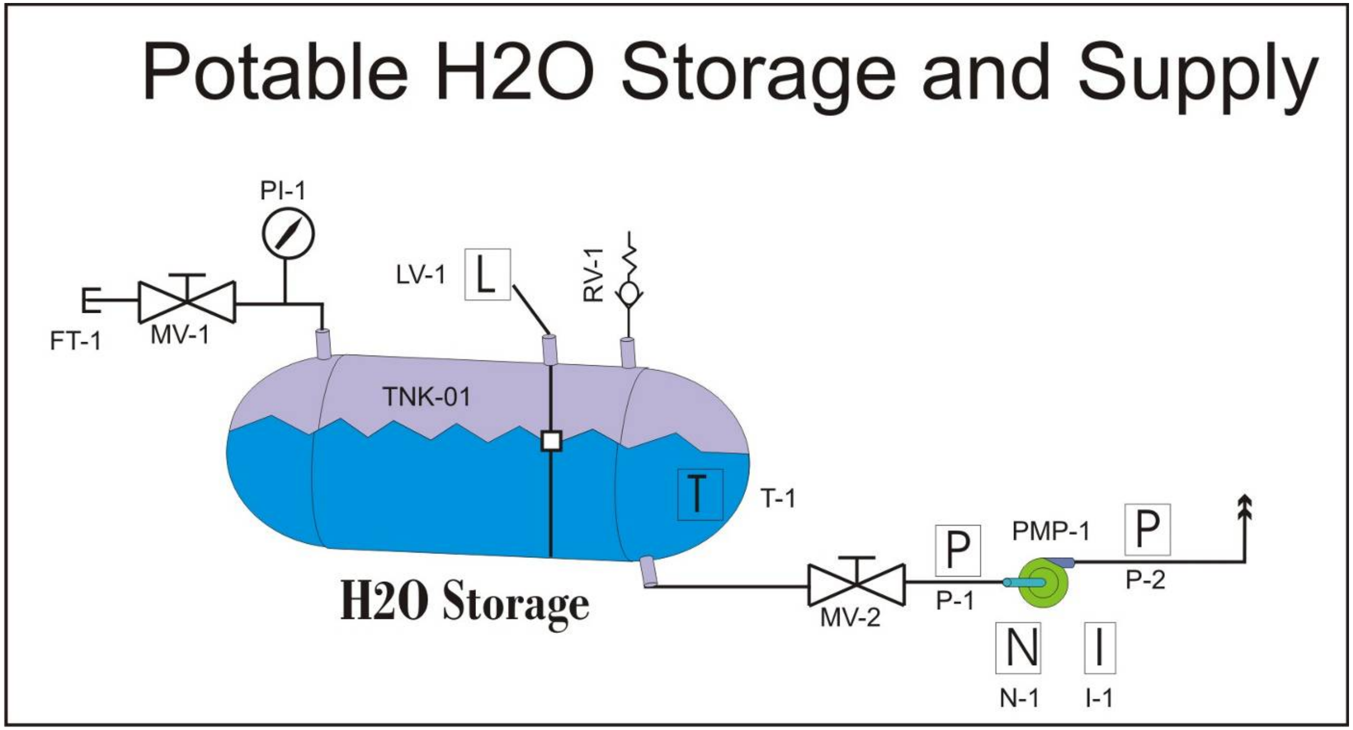
# Water Usage

- Habitat maintains Potable H2O tank, capable of refill, with pump to provide to spigot.
- Not shown - heaters; Heat from PSU may be sufficient to keep from freezing
- Tank should be sized for 2 missions, See Consumables assumptions



# Consumables Assumptions

- Initial unmanned habitat shipped with complete 4 crew, 28 day mission supply
- Each arriving crew brings mission duration additional supply, allowing 28 day contingency
- Water, $O_2$ tanks, and airlock makeup holding tanks for initial missions sized to hold 56 day supply.
- $O_2$ provided by supply tanks (fuel cryo or HP storage) and transferred via compressor to high pressure $O_2$ tankage at habitat. Additional $N_2$ tanks added or swapped at tank farm
- Potable $H_2O$ provided from lander via hose or transfer containers and pumped into habitat low pressure storage tank
- Initial food supply provided as dry food
- Resupply food provided as wet food, $H_2O$ load reduced
- Hygiene supplies include cleaning supplies, wipes, wet and dry disposable towels
- Clothing is disposable with liners. No laundry facilities. Could vacuum desorb/sanitize, however.
- All waste stored in bags/containers. Human waste chemical stabilized. Full bags stored outside habitat in "landfill"

# Waste Collection

- All waste is bagged as it is collected. Full bags are carried outside on Mondays by lowest ranking crew member.
- Human wastes – Collected in "camp toilet" bags:
  - Urine collected in small, single use bags with pretreat in the bag already. Need bag design to minimize "splash" in 1/6 G.
  - All solid wastes and wipes collected via "camp toilet" with pretreat in the bag. Single use bags recommended.
- Wet food trash, oral hygiene waste water, and body hygiene wipes collected in communal wet trash bag.
- Dry towels, used clothing, and all other dry trash collected in communal dry trash bag.

# Consumables Assumptions

- Water, food and O2 dominate consumables
- Dust and other filters, etc. not included

| Consumables Summary | Initial Launch | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Raw Mass | | Packing Factors | | As Shipped | | Resupply w/ PF | |
| | kg | m3 | kg | m3 | kg | m3 | kg | m3 |
| Water | 533.68 | 0.5268 | 0.25 | 0.16 | 667.10 | 0.6111 | 506.10 | 0.4636 |
| O2 - High pressure storage | 97.93 | 0.3020 | 0.30 | 0.30 | 127.30 | 0.3926 | 127.30 | 0.3926 |
| N2 - high pressure storage | 8.16 | 0.0252 | 0.30 | 0.30 | 10.60 | 0.0327 | 10.60 | 0.0327 |
| Dry Food | 69.44 | 0.1258 | 0.05 | 0.10 | 72.91 | 0.1384 | | |
| Wet Food | 198.24 | 0.1908 | 0.05 | 0.07 | | | 208.15 | 0.2042 |
| Toilet Wipes | 18.67 | 0.0192 | 0.05 | 0.05 | 19.60 | 0.0201 | 19.60 | 0.0201 |
| General Wet Wipes | 7.47 | 0.0077 | 0.05 | 0.05 | 7.84 | 0.0080 | 7.84 | 0.0080 |
| Dry Towels | 5.00 | 0.0154 | 0.05 | 0.05 | 5.25 | 0.0162 | 5.25 | 0.0162 |
| Urine Collection Bags | 5.60 | 0.0172 | 0.05 | 0.05 | 5.88 | 0.0181 | 5.88 | 0.0181 |
| Solid Waste Collection Bags | 1.68 | 0.0052 | 0.05 | 0.05 | 1.76 | 0.0054 | 1.76 | 0.0054 |
| Wet Trash Bags | 0.50 | 0.0015 | 0.05 | 0.05 | 0.53 | 0.0016 | 0.53 | 0.0016 |
| Dry Trash Bags | 0.50 | 0.0015 | 0.05 | 0.05 | 0.53 | 0.0016 | 0.53 | 0.0016 |
| | | | | | | | | |
| Water + dry food vs. wet food | | | | | 233.91 | 0.29 | 208.15 | 0.20 |
| Savings | | | | | | | 25.76 | 0.08 |
| Total Hygiene Products | 39.41 | 0.07 | 0.05 | 0.05 | 41.38 | 0.07 | 41.38 | 0.07 |



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# Function / Subsystem Concepts

**Environmental**
- MMSE
- Thermal
- Radiation
- Dust

**Habitat Environment**
- ECLSS
- Water
- Waste
- Food Preparation
- Hygiene
- Consumables

**Habitat Operations**
- Monitoring
- Storage
- Sleeping
- Power and Lighting
- Ingress/Egress
- EVA Operations

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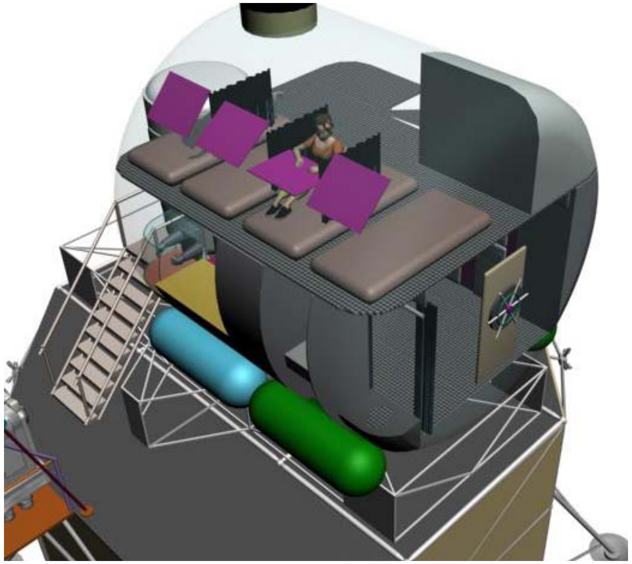
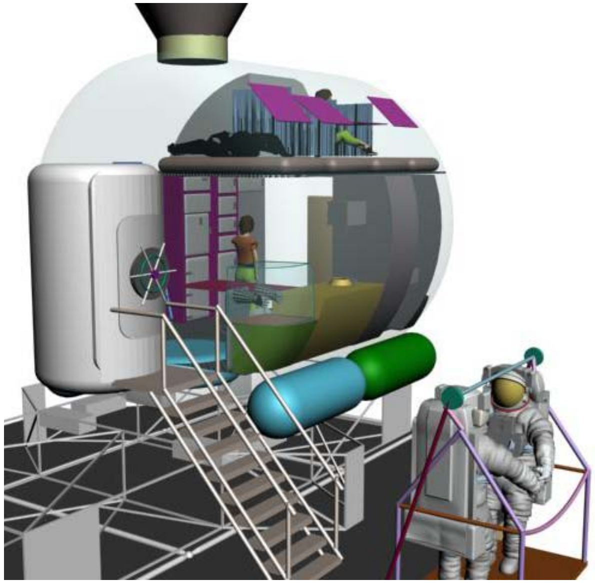
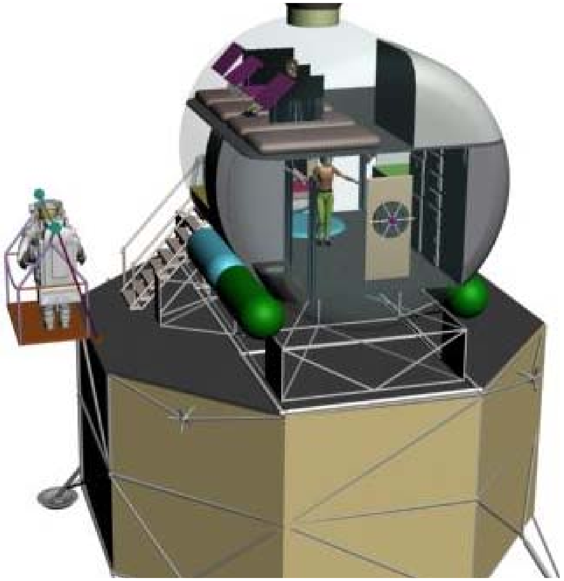
# ECLSS Monitoring

- Sensors for
  - Pressure
  - Temperature
  - Air flow
  - Fan and Pump speed
  - Fan and Pump current
  - $N_2$ Level
  - $O_2$ Level
  - $CO_2$ Level
  - Dust
- Deployment system maintains pressure, monitors tank levels, habitat levels, etc.
- Processing computation uses Lander avionics

# Configuration Trade Study

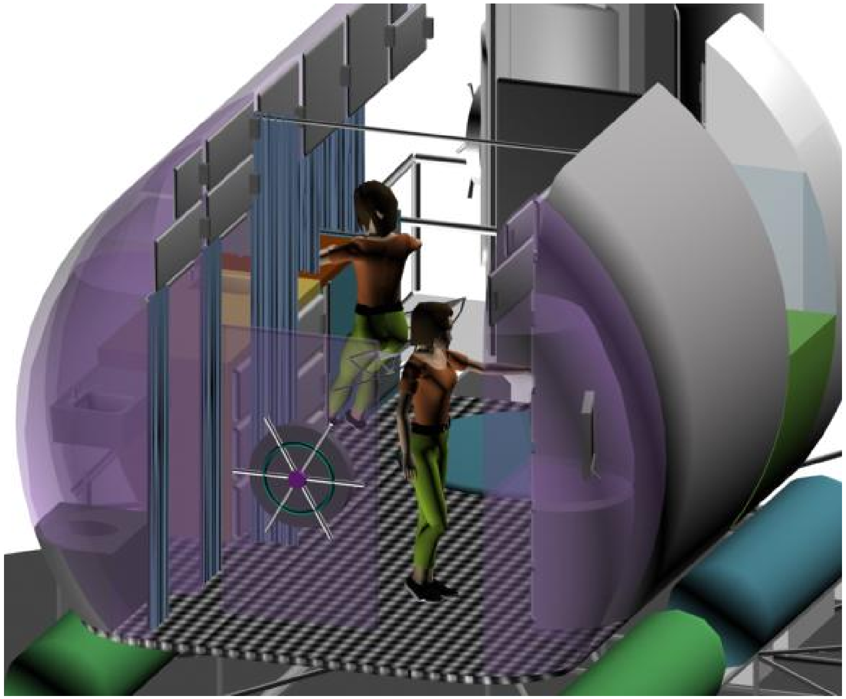


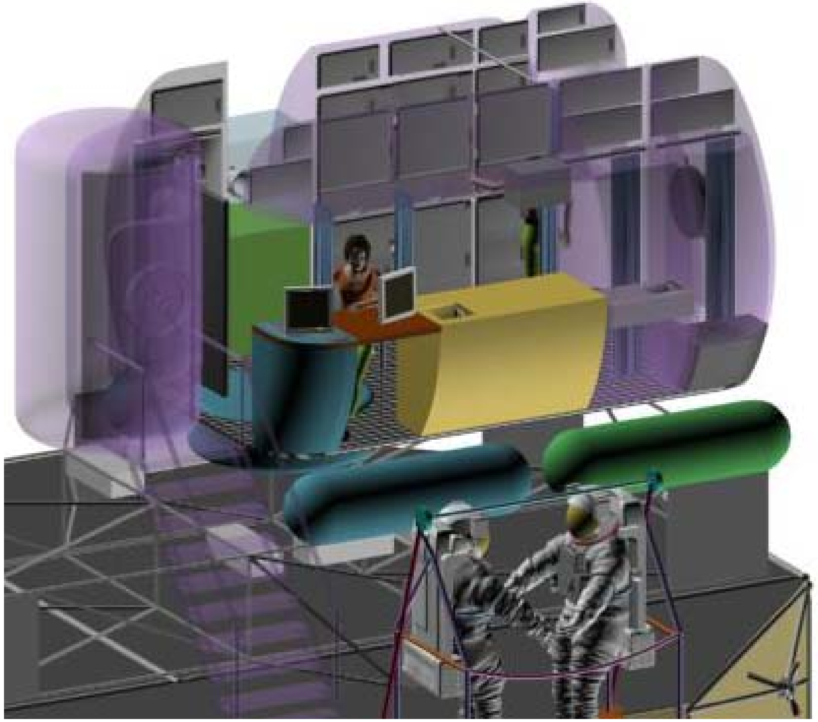




**15 ft Diameter x 15 ft Long MFHE**

# Configuration Trade Study





**12 ft Diameter x 15 ft Long MFHE**

# Storage

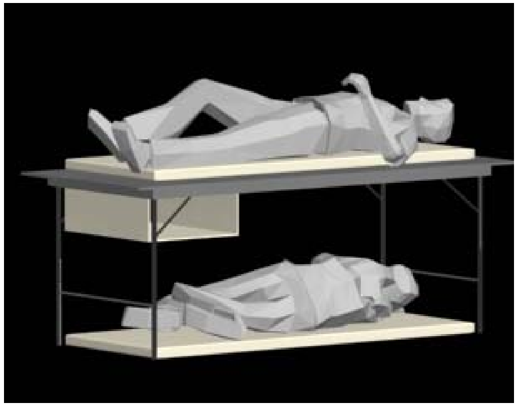
- Storage of necessary items is required inside and outside of the habitat structure
  - Trash and consumable supply tanks may be stored outside
- Conclusion was that bulk storage that minimized packaging would be the best
  - Example is that bulk food stowage would be better over individual servings due to smaller volume required and less packaging material
- Separating bags for wet and dry waste and urine and solid waste would provide better storage and mass savings

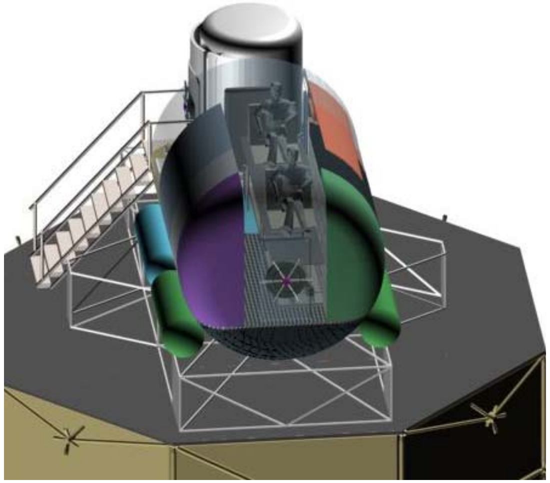
**Bulk Storage vs. Single Servings**

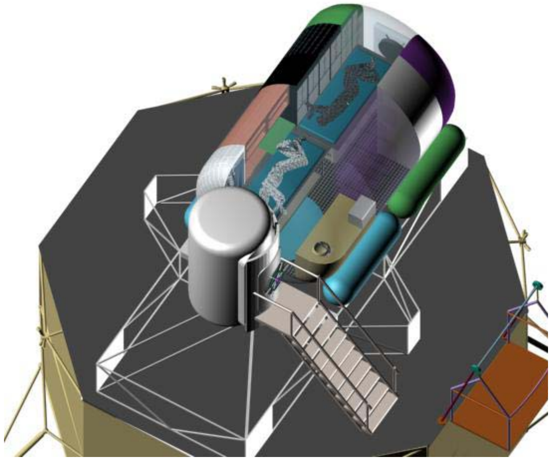
| Figure of Merit Considerations | Bulk Dispersing | Single Servings | Importance | Rationale for Estimating Importance |
|---|---|---|---|---|
| Minimizes trash storage (packaging) | ● | ○ | H | Short missions- volume and/or mass limited |
| Minimizes preparation processing/time | ○ | ● | L | |
| Optimizes food stowage volume | ● | ○ | H | |
| Minimizes contamination/spoilage risk | ○ | ● | M | |
| Optimizes menu choices (habitability) | ○ | ● | M | |
| | Solutions | | | |

# Sleep Accommodations

- For a minimum approach, no personal area will be set aside for sleeping quarters.
- Instead a common area will be used for sleep accommodations along with a personal sleeping bag.
- Future growth options will explore the idea of a personal area for sleeping and downtime.







# Power and Lighting

- Conditioned power provided by PSU;
- Power provided to all ECLSS and Habitat monitoring sensors and actuators
- Only critical controlled devices have hardwired control lines, all others are just wireless nodes on the network
- Simple Power Management And Distribution (PMAD) unit required to achieve Habitat minimum functionality:
  - Power and return to each load
  - Automatic switched loads routed through PMAD to ECLSS functions
  - PMAD Power provided to lighting through Manual switched loads
  - PMAD unit on wireless network for network control of automatic switched loads
  - PMAD provides current limiting/short circuit protection
- Additional functionality for deployment:
  - 115V 60Hz Inverter provided for personal items (crew computers, entertainment devices, battery (e.g. camera, VCR, toothbrush) chargers

# Ingress/Egress Trade

| Solution Set \ FOM Criteria | | Element Mass | Launch Volume | Power | Consumable Mass Loss | Complexity | Integration of Other Subsystems | Growth Potential | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Weight *(1 low 10 high)* | | *10.0* | *8.0* | *2.0* | *9.0* | *2.0* | *4.0* | *3.0* | |
| Airlock | *Score* | 6 | 7 | 6 | 5 | 8 | 7 | 6 | ***235*** |
| Suit Port, Clean room, Door | *Score* | 5 | 6 | 8 | 7 | 6 | 6 | 4 | ***225*** |
| Small Airlock, Clean room | *Score* | 5 | 5 | 6 | 6 | 7 | 5 | 6 | ***208*** |
| Suit Port, Box, Door, Clean room | *Score* | 6 | 6 | 7 | 7 | 6 | 4 | 3 | ***222*** |
| Door, Clean room | *Score* | 7 | 9 | 5 | 1 | 6 | 8 | 6 | ***223*** |

- Airlock – Full service and functional ingress/egress method
- Suit Port – Rear entry suit on habitat wall
- Clean room – Inside habitat used for maintenance and contain dust
- Door – Simply door that vents habitat. Apollo design.
- Box – Small door with glove bag for sample ingress/egress

*Due to multifunctional aspects the Airlock Design falls out as optimal.*

- EVA Operations
  - EVA activities were a primary driver in the habitat configuration trades
  - Habitat element must provide functions related to surface excursions for the mission duration
  - Space suit accommodation for donning, doffing, servicing, maintenance and repair were addressed
    - Current Constellation lunar space suit configuration assumed
      - Rear entry, modular
    - Habitat configuration optimized for minimizing air loss, minimizing dust migration into the habitat and acceptable areas and volumes for suit related operations

# Habitat Operations

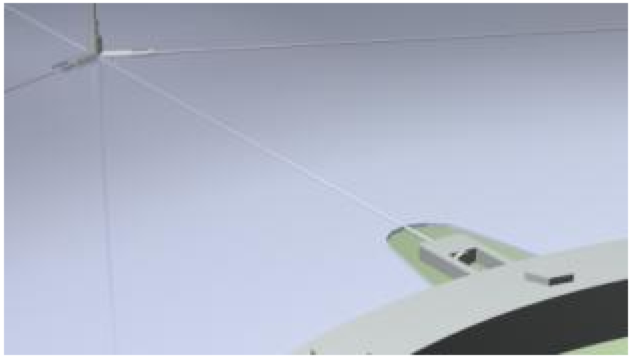
- EVA suit support and service – Equipment related
  - Expendable recharging
    - Recharge capability within airlock. Panel interface similar to umbilical operation interfaces
  - Maintenance
    - Nominal operations performed within the airlock.
      - Cleaning, seal lube, drying
  - Repair
    - Repair component placed inside ‘isolation bag’ (different from storage bag), brought into living volume
      - Cut bag open enough to ‘operate’ on component, minimizing dust exposure inside the living volume
      - Repair kit operations, spare part replacements

# Habitat Operations

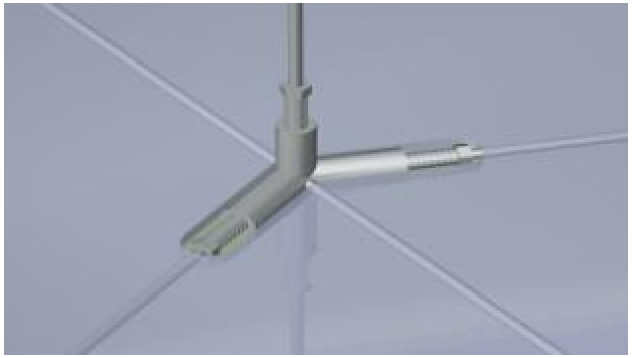
- EVA suit support and service – Sizing
  - Expendable recharging
    - Recharge panel, 2 recharging station
    - Expendables mass / volume are accounted for in the LSS
  - Maintenance
    - Vacuum / air blower system mounted in airlock
    - 0.25 $Ft^3$ volume for maintenance items
      - Lube, visor brush, swabs
  - Repair
    - Repair / spare parts, 1.0 $ft^3$
      - 2 visor assemblies (4 lbs@), 2 pair over-gloves and misc. seals (1 lbs total)
    - Tools– 'standard' kit used for habitat and suit work
      - 2 $ft^3$ 10 lbs (engineering estimate)

# Habitat Operations

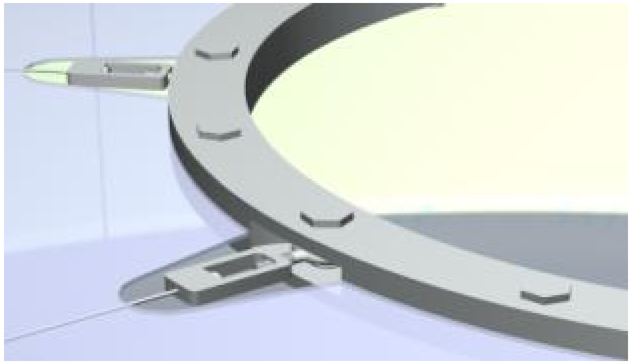
- EVA Operations – Activity related
  - Airlock volume provides nominal two crew ingress/egress operations
    - Allows donning and doffing of the suits in the airlock (2 crew at a time)
    - Storage bags for suit allow temporary storage of suits in habitat
      - When airlock being used by other two crew
    - Suit storage nominally in the airlock
    - Similar in operation to the Altair configuration for 2 crew
    - Minimal time entire crew would be split up. Schedule specific activities to not reduce work efficiency
  - Non-nominal operation
    - If all crew needed to ingress/egress at once they could fit in the airlock volume once suited
    - Suit donning/doffing would be performed (by at least two members) inside the habitat volume
      - Dust mitigation benefit of airlock is reduced



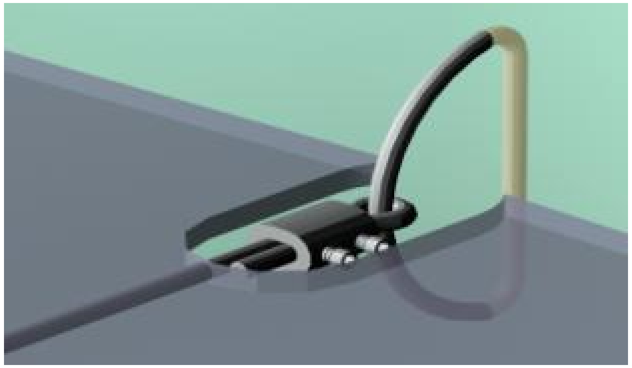
Tension Ring Interface



Typical Connector



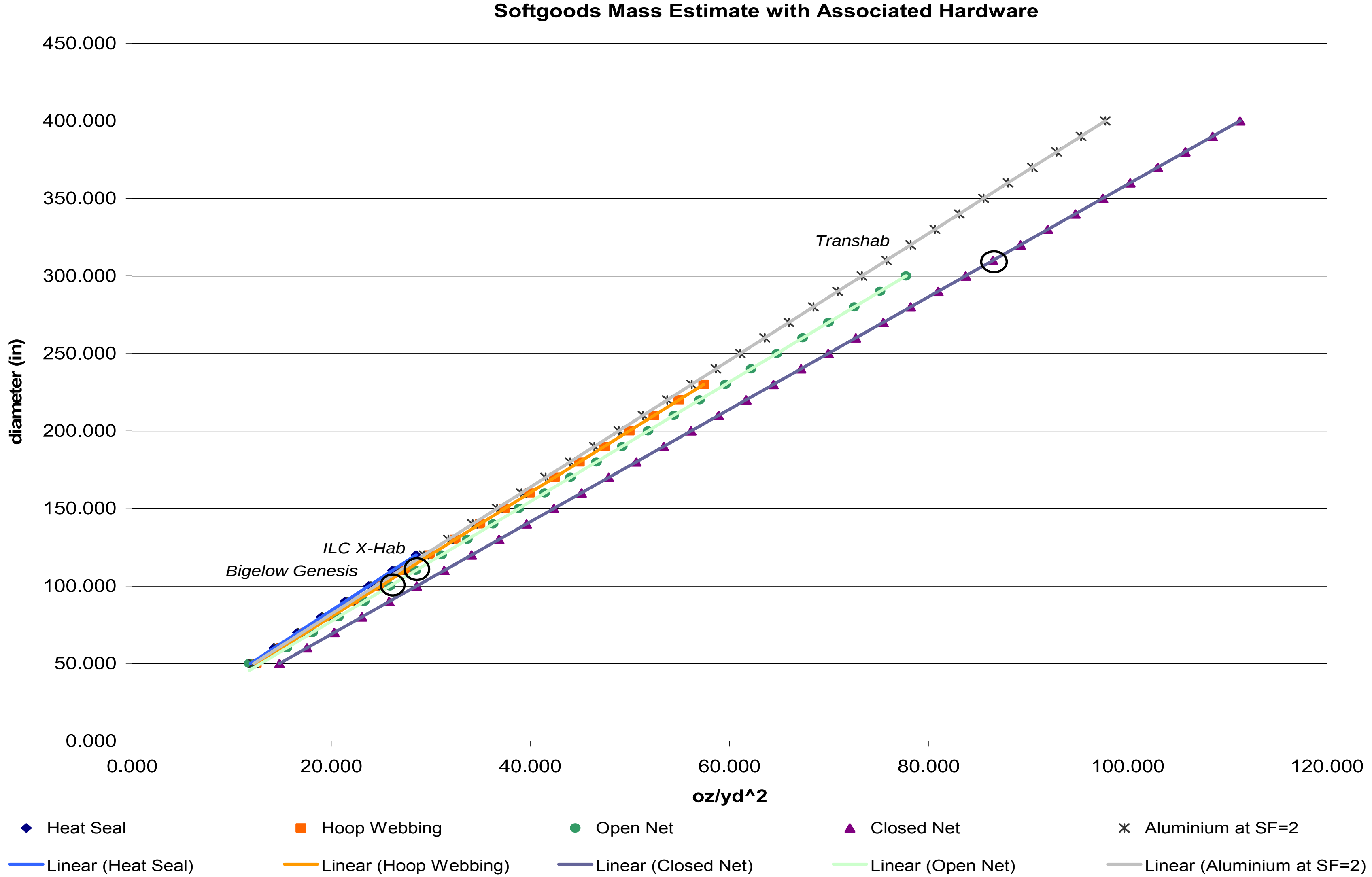
Tension Ring Interface



Detail at Enclosure Interface

## Trampoline Floor Details

# Softgoods Mass Study



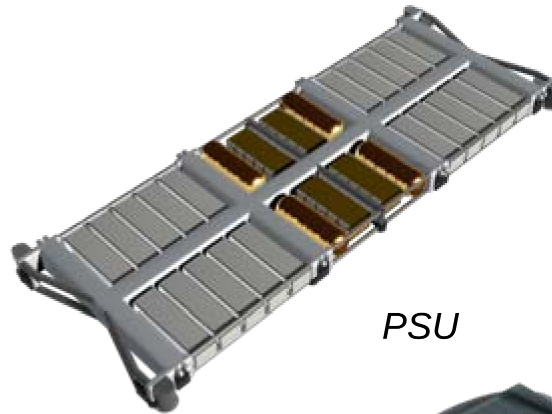



SICSA Sasakawa International Center for Space Architecture

ILC DOVER creating what's next

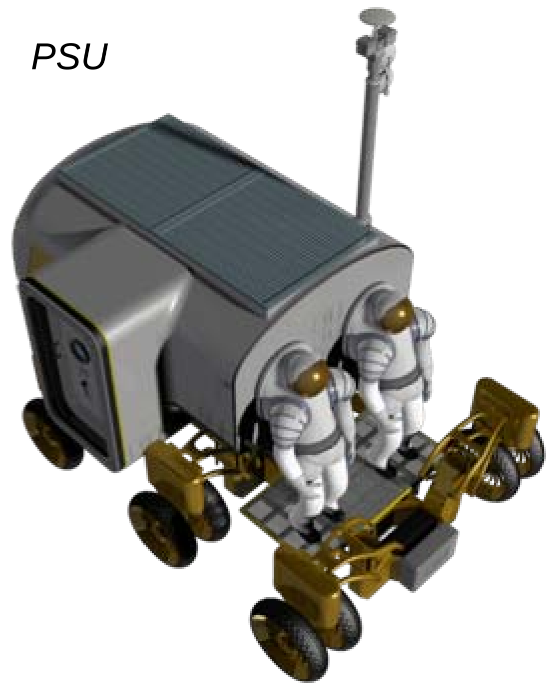
Hamilton Sundstrand A United Technologies Company

# MFHE Interface Surface Elements



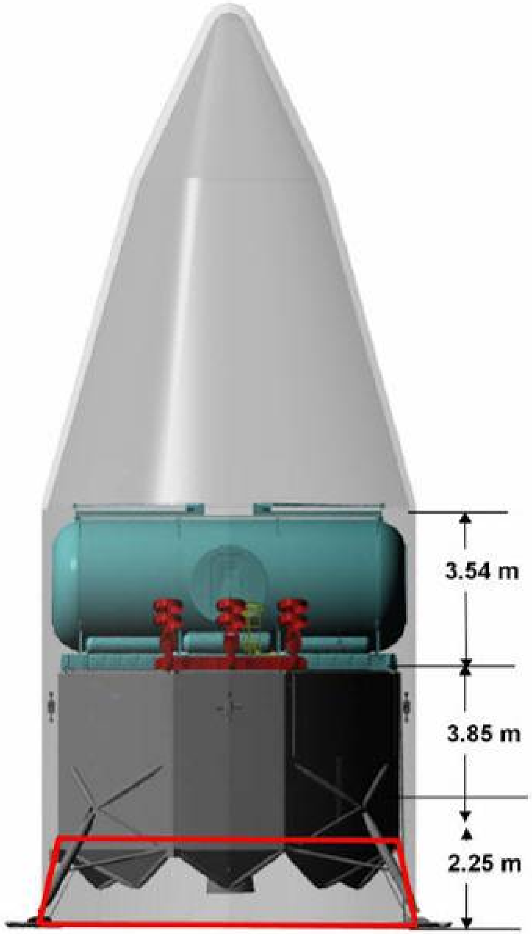
*PSU*

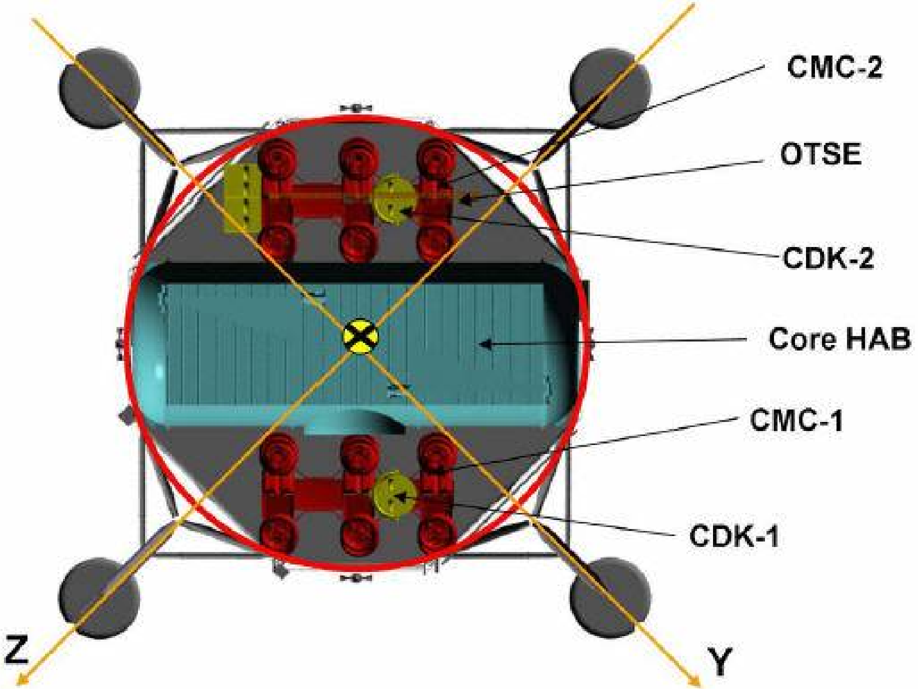
*HLM: Two Tri-ATHLETEs*



*SPR with Mobility Chassis*

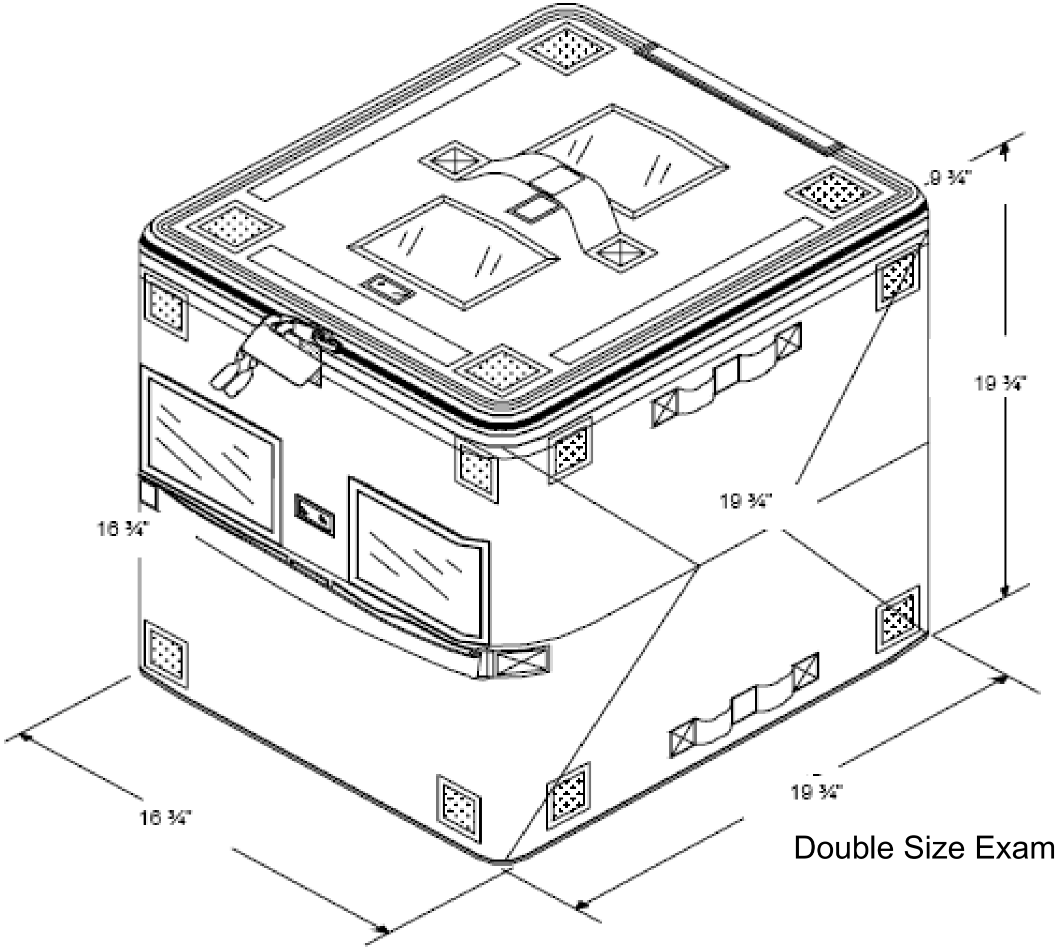
# MFHE Cargo Manifest




Cargo Mission – Core Habitat

# CTB




Double Size Example

Photo: Representation of HTV Resupply Rack (HRR)

# Acronyms

| Acronym | Name |
|---|---|
| HLM | Heavy Lift Mobility System |
| ATHLETE | All-Terrain Hex-Legged Extra-Terrestrial Explorer |
| CDK | Chassis Driving Kit |
| CMC | Crew Mobility Chassis |
| DPLM | Disposable Pressurized Logistics Module |
| LCT | Lunar Communications Terminal |
| MCT | Mobility Chassis Toolkit |
| MFHE | Minimum Functionality Habitation Element |
| MPU | Mobile Power Unit |
| OPS | Oxygen Production System |
| OTSE | Offloading & Transportation Support Equipment |
| PSU | Power & Support Unit |
| RPLM | Reusable Pressurized Logistics Module |
| SPR | Small Pressurized Rover |
| BFO | Blood Forming Organs |
| ECLSS | Environmental Control and Life Support System |
| PMAD | Power Management and Distribution |
| WEI | Work Efficiency Index |
| MMSE | Micro Meteoroid and System Ejecta |
| CTB | Cargo Transfer Bag |
| EVA | Extra Vehicular Activity |
| IVA | Inner Vehicular Activity |

# Resources


Eckart, Peter. *Spaceflight Life Support and Biospherics*. Microcosm Press, California: 1996.

Dorsey, J. T., Wu, K. C., Smith, R. “Structural Definition and Mass Estimation of Lunar Surface Habitats for the Lunar Architecture Team Phase 2 (LAT-2) Study”, *Earth and Space Conference 2008,* Long Beach, CA, 2008.

*Kennedy, Kriss (2002). “Lessons from TransHab: An Architect's Experience”. AIAA Space Architecture Symposium. AIAA 2002-6105.*

Cadogan, D.P., Scheir, C., “Expandable Habitat Technology Demonstration for Lunar and Antarctic Applications”, 2008-01-2024, International Conference on Environmental Systems, San Francisco CA ,29 June – 2 July 2008.

“Surface Architecture Reference Document (SARD)”. V.3.4 12 Sept 08.

Barta, Daniel and Michael Ewert. “Life Support Systems for Human Lunar Missions”. *AIAA Space 2008 Presentation*.

9 Sept 08.

Christiansen, Eric. “MMSE Protection for Lunar Surface Habitats” 22 April 07.

“Center of Mass Estimates”. 12 May 08.